controller shaft and are driven by a pin working in a slot, so that when the controller handle is turned in a counter-clockwise direction, equivalent to moving the controller contacts to the right, the loose segments hang back while the controller handle is moved over three notches, and on succeeding notches occupy the positions shown by the dotted lines. The effect of this special arrangement is to short-circuit the series resistance on notches *12*, *11*, *10*, *3*, *2*, and *1*, so that the armature circuit can be opened when the motors are switched out of parallel, and when the controller is returned to the off-position from notch *1*, with no resistance in the armature circuit.

106. Connections for Rheostatic Braking. — When the controller handle is moved in a counter-clockwise direction to the rheostatic brake notch *1*, the reversing drum being in the forward position and the brake drum on the brake notch, the path of the current is as follows: Earth at *G*–terminal *G*–finger *G*–reversing drum–finger *31*–brake drum–

finger *F1*–terminal *F1*–*F1*–series field of motor *1*–*FF1*–terminal *FF1*–finger *FF1*–

finger *F2*–terminal *F2*–*F2*–series field of motor *2*–*FF2*–terminal *FF2*–finger *FF2*–

brake drum–

finger *26*–*26*–main drum–finger *25*–*25*–reversing drum–finger *AA1*–terminal *AA1*–*AA1* armature of motor *1*–*A1*–terminal *A1*–finger *A1*–reversing drum–finger *23*–*23*–

finger *27*–*27*–main drum–finger *28*–*28*–reversing drum–finger *AA2*–terminal *AA2*–*AA2* armature of motor *2*–*A2*–terminal *A2*–finger *A2*–reversing drum–finger *24*–*24*–

main drum–finger *R6*–series resistance *R6* to *R2*–finger *R2*–main drum–finger *22*–brake drum–finger *31*–*31*–reversing drum–finger *G*–terminal *G*–earth at *G*.

On the second brake notch *2* finger *R4* makes contact with a segment of the main drum and short-circuits all the resistance excepting that between *R6* and *R4*. On the third braking notch *3* all the resistance is short-circuited.

DIRECT-CURRENT RAILWAYS

(PART 1)

PRINCIPLES OF DESIGN

TYPES OF RAILWAYS

INTRODUCTION

1. Differences Between Tramways and Railways. — Electric railways might be said to be enlarged tramways, for the apparatus was first developed from that used on tramways, but modern lines show many differences. A fundamental one is that tramways run along main roads, while railways usually have their own private right of way. Other differences, in addition to cost, are: the railway rolling stock runs at a higher speed, has definite stopping places, and is arranged in trains, with suitable system of control. The railway staff is also similar to that required by the Board of Trade for steam railways, and there must be an adequate signalling system. Further, in order to obtain the authorization to construct a railway, a different Parliamentary procedure is necessary.

In addition to the passenger service, many electric locomotives are in use for shunting purposes and for hauling wagons round collieries, iron and steel works, factories, etc., and for connecting a works or mine with a main-line railway. All the early railways were worked with 500-volt direct current, the same as tramways, but the excessive current required at that voltage has led to the adoption of higher pressure, and in some cases 1,200 volts is used.

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2. Development of Electric Railways.—With the exception of the Liverpool Overhead and the Mersey Tunnel Railways, the early history of electric-railway enterprise in Great Britain has coincided with the development of underground railways in London. The congestion of surface traffic in the streets of that city and the impossibility of obtaining private rights of way in the densely-populated parts caused the railways to be placed in deep-level tunnels, or tubes. These tubes are reached by means of lifts, worked in most cases by electricity.

The first of these underground railways, the City & South London, opened in November, 1890, runs through two tubes $9\frac{1}{2}$ feet in diameter. The locomotive weighs $13\frac{1}{2}$ tons, and each coach, when loaded, weighs 30 tons. The average train speed is 15 miles per hour. Cast-iron hinged shoes fastened to the locomotive take direct current at 500 volts from a steel contact rail supported on insulators between the track rails. The track rails form the return mains, being bonded with copper. The feeders for the northern extensions to this line are supplied with current at 2,000 volts by a combination of the three-wire and five-wire systems. Motor generators reduce the pressure to 500 volts on the third rail, and a large storage battery is also used to equalize the load at the power house.

3. Central London Railway.—The Central London Railway is so constructed and the stations so placed that the trains run into them against a grade of 1 in 60, the departing trains being favoured by a grade of 1 in 30. This arrangement greatly economizes the energy required to operate the trains. When this railway was first opened, electric locomotives with gearless motors were used, but they caused such vibrations in the buildings directly over the tube that they had to be abandoned, and the trains now consist of motor coaches and trailer cars. Three substations supply current to the line, and rotary converters in these stations change the 5,000-volt three-phase alternating current from the power house into direct current at a pressure of 550 volts.

4. Electric Locomotives.—At first the motors of electric locomotives were mounted concentrically with the axle; but as the

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TABLE I

DIRECT-CURRENT ELECTRIC RAILWAYS IN GREAT BRITAIN

Name of Railway	System Rail	Length Miles	Sharpest Curve Feet Radius	Maximum Grade	Average Distance Between Stations Yards	Voltage	Average Speed Miles Per Hour	Weight of Track Rail Pounds Per Yard
City & South London	3rd	7·2	350	1 in 50	700	500	15	80
Liverpool Overhead	3rd	6·5	430	1 in 40	670	500	19	56
Waterloo & City, London	3rd	1·5	330	1 in 30	2,640	500	18	86
Central London	3rd	6·3	330	1 in 30	800	550	$15\frac{1}{2}$	100
Mersey Tunnel	3rd and 4th	4·6	530	1 in 27	1,300	600	19	86
Great Northern & City, London	3rd and 4th	3·4	395	1 in 52	1,200	600	15	86
Liverpool to Southport Section, Lancashire & Yorkshire	3rd and 4th	33·0		1 in 85	2,200	600	30	86
Tyneside Lines of North Eastern	3rd	38·0	660	1 in 27	2,200	600	22	90
Metropolitan, London	3rd and 4th	30·0	360	1 in 40	2,200	600	22	86
Metropolitan District, London	3rd and 4th	24·3	330	1 in 40	1,160	600	17	86
Baker Street & Waterloo, London	3rd and 4th	4·2	330	1 in 30	880	600	14	90
Great Western & West London	3rd and 4th	4·7	400	1 in 60	1,000	600	16	97
Great Northern & Piccadilly, London	3rd and 4th	9·2	400	1 in 50	700	600	14	90
Charing Cross & Hampstead, London	3rd and 4th	7·7	400	1 in 60	880	600	14	90

power demand increased, it became impossible to find sufficient space for the motors, and the geared type had to be used. Locomotives are now produced in which the motors drive through connecting-rods and the track wheels are coupled together. This arrangement allows the motor to be placed well above the axle, thus raising the centre of gravity and lessening the wear and tear on the track.

In 1894, a self-contained electric locomotive was produced by Heilmann. This consisted of a 600-horsepower quick-speed steam engine driving a dynamo the output of which was 1,000 amperes at 400 volts. The current was supplied to motors mounted on the axles, and when tested the locomotive drew trains weighing 200 tons at a speed of 62 miles an hour. The type went out of use until recently, when the North British Railway have experimented with a locomotive using a steam turbine, instead of a quick-speed engine, as the prime mover.

5. Regeneration.—When the three-phase system was first applied to the working of Swiss mountain railways, it was found that a descending train could return energy to the line and thus be kept absolutely in check. This idea has since been developed under the name of **recuperation**, or **regeneration**, and some engineers think it will be a factor favourable to the electrification of railways on a large scale. It has already been successfully applied to several tramways working with direct current in Great Britain, as well as to three-phase railways.

Constructional and other details of the best-known direct-current electric railways in Great Britain are given in Table I.

CALCULATIONS

CYCLE OF OPERATIONS

6. Character of Service.—On urban and suburban lines there exists regular and constant working throughout the day, and the motors and other electrical apparatus must perform a definite cycle of operations with little variation; the trains are also

frequently started and stopped. On interurban railways, that is, railways running across country to connect several towns, the service is not so frequent and the trains run much faster than urban trains. They also start and stop much less frequently, and the motor equipments are often made to work with two systems and voltages, namely, direct current at 550 volts and single-phase alternating current at 1,000, or more, volts. For main-line railways the rolling stock is much heavier than for any of the foregoing, and the motors, controllers, and other apparatus must be very powerful. Quick acceleration is not important, but the motors must be capable of running for long periods on a fairly steady load without overheating.

In the case of *industrial railways*, regularity of working is conspicuously absent. The loading on the motors varies with the amount of goods to be hauled, and as a rule no time schedule must be kept. Locomotives are sometimes used for shunting wagons and coaches at terminal stations; their motor equipments must, of course, be capable of handling very irregular loads.

7. Operations of Urban and Suburban Railways.—The actual cycle of operations performed by an electric train in the regular class of urban and suburban service consists of: acceleration from rest; free or steady running with the current on; coasting, or running with current off; braking, or regenerating and braking; and standing in station.

Acceleration is the period during which the train starts from rest and reaches a more or less uniform speed. In this period, the output of the motors is chiefly utilized in imparting to the train the required velocity and in overcoming resistance to motion. The **free-running** or steady-running period includes the time during which approximately constant speed is maintained. In many cases, where stations are very close together, this period is omitted, there being no interval between the accelerating period and the coasting of the train. During the **coasting period** power is cut off from the propelling motors and the train is allowed to run by its own momentum. **Braking** is sometimes effected electrically by recuperation or return of

energy to the line, instead of mechanically by pressing brake blocks on to the wheels.

8. Averaging the Cycle.—Although the various parts of the cycle of operations of an electric railway are always present, with the possible exception of the free running, the duration of each part may vary within certain limits every time the cycle is performed. But it is generally sufficiently accurate to disregard these variations and to assume that the same cycle is performed each time, the duration of each part being taken as the average lengths of those parts in all the cycles. For example, suppose that a train must run from one terminus to the other in 26 minutes, stopping for 20 seconds at twelve intermediate stations.

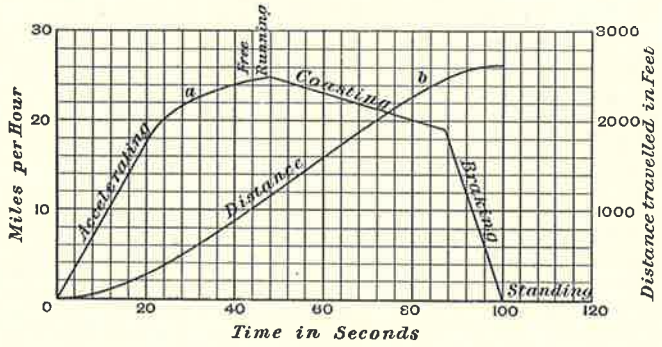

FIG. 1

If the distances between consecutive stations vary from 600 to 1,300 yards, and the total distance between the termini is $6\frac{1}{2}$ miles, the average distance between stations is 880 yards. As there are thirteen cycles, the average cycle consists of covering 880 yards in 2 minutes from start to start.

9. Speed-Time and Time-Distance Curves.—The cycle of operations on an electric railway may be shown by the curves in Fig. 1. Time, in seconds, is plotted as abscissæ, and the speed, in miles per hour, and the distance travelled, in feet, are plotted as ordinates. Curve *a* represents speed, and shows how it varies throughout the time of one cycle; curve *b* represents distance from the start, and indicates the position of the train at any

moment. Thus, 40 seconds from the start the train has travelled 900 feet, for the ordinate from 40 seconds crosses curve *b* at the point 900, the reading for distance being on the right-hand scale. The actual velocity at that instant is found by following the ordinate from 40 seconds until it crosses curve *a* and reading off the value on the left-hand scale; this will be found to be 24 miles per hour. The same set of curves may be used to show the five periods composing the cycle of operations. Thus it is seen that the accelerating period lasts 40 seconds, the free-running period lasts 8 seconds, the coasting period lasts 39 seconds, the braking period lasts 13 seconds, and finally the standing period lasts 20 seconds.

TRACTIVE RESISTANCE

10. Journal, Track, and Air Friction.—Unless supplied with power, a train moving on a level track will gradually lose its speed owing to **tractive resistance,** or the resistance to motion. This resistance is due to the friction of the axles in the bearings, or **journal friction,** to the resistance to the wheels rolling on the rails, or **track friction,** and to the resistance to the movement of the train through the atmosphere, or **air friction.**

Let A = journal friction, in pounds per ton;
B = constant for track friction;
C = constant for air friction;
D = tractive resistance, in pounds per ton;
V = speed of train, in miles per hour.

Then, $$D = A + B\,V + C\,V^2$$

For the best modern main-line rolling stock, A may be taken as 4, but its value must sometimes be taken as great as 15. For such stock as colliery tubs it often reaches 40, and for contractors' tubs on light temporary tracks it reaches an even higher figure. For best conditions, B is given a value of ·12; and $C = \dfrac{\cdot 00035\,Q\,(7+n)}{W}$, in which n represents the number of coaches in the train, Q is the area of the front of the train, in square feet, and W, the weight of the train, in tons.

EXAMPLE.—What is the tractive resistance of a 10-coach train that weighs 240 tons and has a front area of 85 square feet travelling at a speed of: (*a*) 10 miles per hour? (*b*) 30 miles per hour?

SOLUTION.—(*a*) To apply the formula just given, $A = 4$, $B = \cdot 12$, $C = \frac{\cdot 00035 \times 85 \times (7 + 10)}{240} = \frac{\cdot 00035 \times 85 \times 17}{240} = \cdot 0021$. Then, if V = 10 mi. an hr., the tractive resistance

$$D = 4 + (\cdot 12 \times 10) + (\cdot 0021 \times 10^2) = 5 \cdot 41 \text{ lb. per ton.}$$ Ans.

(*b*) If $V = 30$, the tractive resistance

$$D = 4 + (\cdot 12 \times 30) + (\cdot 0021 \times 30^2) = 9 \cdot 49 \text{ lb. per ton.}$$ Ans.

11. Tractive Resistance of Wagons.—The tractive resistance of the wagons or trucks will vary between wide limits. The lowest values will be found with trucks equipped with roller bearings, such as are used on the North Eastern Railway, which at moderate speeds have a tractive resistance of 5 or 6 pounds per ton. With ordinary goods wagons, a probable value is 8 to 10 pounds per ton. For coal trucks and small wagons the resistance will be from 12 to 18 pounds per ton. Much naturally depends on the construction and nature of the bearings and the lubrication, which in small trucks is usually very poor. In a recent case, it was found that the tractive resistance of a train of colliery tubs, each weighing 13 hundredweights when loaded, was as high as 45 pounds per ton.

12. Train Friction.—The curves in Fig. 2 show the **train friction** of trains consisting of from one to five 45-ton coaches that have an effectual cross-sectional area of 110 square feet. They show that a single coach running at 75 miles per hour has a resistance of $62\frac{1}{2}$ pounds per ton, whereas a two-coach train has a resistance of only $41\frac{1}{4}$ pounds per ton. The journal friction of 5 pounds per ton is the same for all speeds, and is represented by a vertical dotted line. The track friction varies with the unevenness of the track and increases with the speed; it is shown by the slanting dotted line. The distance between the vertical and slanting dotted lines at any speed represents the track friction for that speed. The distance between the track-friction line and the vertical line passing through *0* represents the journal and track frictions combined. The distance between the dotted slanting line and the curved full lines represents the

air resistance for trains made up of different numbers of cars. With a single-coach train, travelling at a speed of 35 miles per

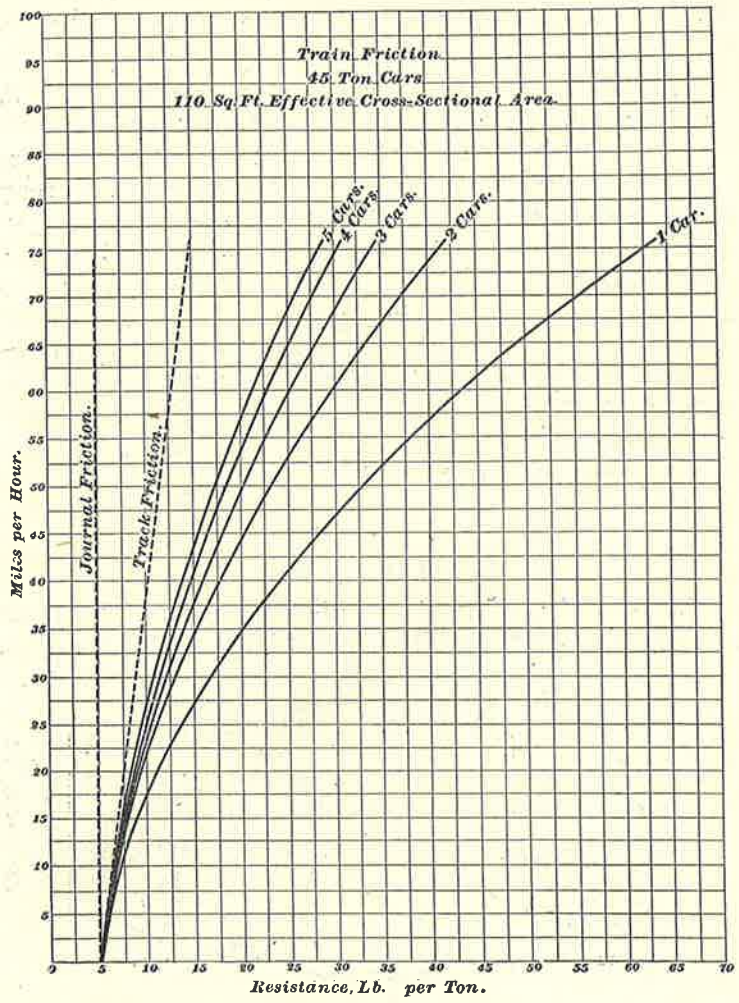

FIG. 2

hour, the air friction is about 11 pounds per ton. The resistance increases rapidly with increasing speeds, but its effects are not as pronounced with heavy trains as with light, because the end

area is practically the same, and the proportion of the total power used in overcoming air friction is therefore less. These curves show that, as regards power consumption, it is more economical to run coaches in trains than singly, especially for high speeds.

13. Influence of Track Curves.—Curves greatly increase the tractive resistance of the train, but the actual amount of this increase cannot be easily obtained, for it depends on the sharpness of the curve and the condition of the roadbed. As a rough approximation, it may be assumed that on a level curve in good order with a 500-foot radius, a train of from 6 to 10 six-wheeled coaches will be opposed by an extra resistance to traction of about 12 pounds for every ton weight of the train. For a radius of 1,000 feet, the extra resistance will be 6 pounds; for a radius of 1,500 feet, 4 pounds; and for 2,000 feet, about 3 pounds. For main-line traffic, railway engineers try to keep the minimum radius of curvature at $\frac{1}{2}$ mile, when the extra resistance is about $2\frac{1}{3}$ pounds per ton weight of train.

ACCELERATION

14. Comparison of Steam and Electric Traction.—One of the strongest arguments in favour of electricity as a motive power

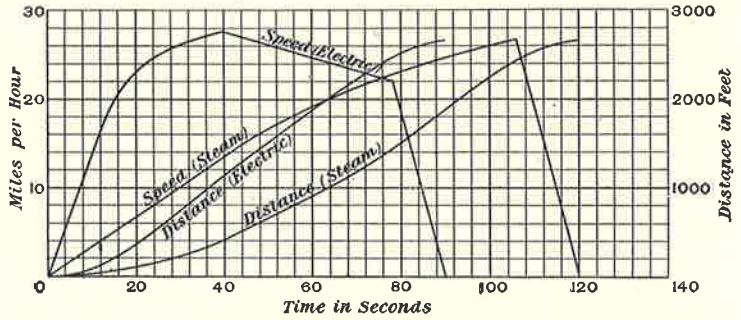

FIG. 3

for railways is that it gives rapid **acceleration,** or the ability to speed up quickly. This enables electric trains on urban and suburban railways to run at a higher average speed than is

possible with steam locomotives, and this is an important advantage where the stations are only $\frac{1}{2}$ or 1 mile apart, as is the case with many of the electric railways of Great Britain. In Fig. 3 are given the speed-time and time-distance curves of steam and electric trains that start from rest and run $\frac{1}{2}$ mile. The electric train has an initial acceleration of 2 feet per second per second; the steam train has an initial acceleration of $\frac{1}{2}$ foot per second per second. This enables the electric train to reach its greatest speed in 40 seconds, coast for 38 seconds, reaching the station in 90 seconds from the start, whereas the steam train only reaches its maximum speed in 106 seconds, when it must immediately brake, and it reaches the station in 120 seconds from the start.

15. Advantages of Quick Acceleration.—The advantages of quick acceleration are an increased train mileage per day or per annum, which gives an increased power of earning money for the same number of trains, the same staff, the same track, and an increase of about 28 per cent. in the average speed. The increase in average speed, giving a consequent saving in time, is a considerable attraction to possible passengers in view of competition with other means of conveyance, such as tramways and motor buses. On long-distance railways, where stops are infrequent, and on industrial railways quick acceleration is not so important.

16. Force Required to Accelerate.—As speed is usually measured in miles per hour or in feet per second, acceleration is expressed in terms of miles per hour per second or feet per second per second. For example, if a train starts from rest and acquires a speed of 30 miles per hour in 25 seconds, the acceleration is 1·2 miles per hour per second, or 1·76 feet per second per second.

Let P = force, in pounds per ton;
W = weight of train or other body, in pounds;
f = acceleration desired, in feet per second per second;
g = acceleration due to gravity.

Then, the force required to produce any desired acceleration is

$$P = \frac{W f}{g} \qquad (1)$$

This formula shows that the acceleration is strictly proportional to the force producing it. Thus, if the value of P is one-half the value of W, the rate of acceleration is 16·1 feet per second per second, or one-half that due to gravity. For a weight of 1 ton and an acceleration of 1 foot per second per second, the value of P is 69·5, or roughly 70, pounds per ton. The foregoing formula may therefore be written

$$P = 70f \qquad (2)$$

But if the rate of acceleration f' is desired in miles per hour per second, the formula becomes

$$P = 102f' \qquad (3)$$

The force given by these formulæ must in all cases be added to the force necessary to overcome the tractive resistance, which is easily found by multiplying the assumed or calculated number of pounds per ton by the total weight of the train, in tons.

17. Rotational Acceleration.—When a train must be accelerated from rest, it is necessary to set in motion not only the train, but also the wheels and axles and the armatures of the driving motors in a rotational sense, and after the train is in motion it possesses momentum by reason of its linear velocity and by reason of the rotation of all its revolving parts. Both of these components of the total stored energy, therefore, must be supplied by means of the accelerating force. The force required for **rotational acceleration** is proportional to that required for ordinary or **translational acceleration,** since the two accelerations are proportional; this additional force is generally taken as one-tenth of that required for translational acceleration.

18. Force to Overcome Gravity.—When it is required to accelerate a train up a gradient, an additional force must be applied equal to the gravity component due to the gradient. The gradient may be expressed as $\frac{\text{rise of incline, in feet}}{\text{length of incline, in feet}}$.

Let W_t = weight of train, in tons;
G = gradient expressed as a fraction;
F_w = force required to overcome weight of car acting down the gradient, in pounds.

Then, $$F_w = 2{,}240\, W_t G$$

EXAMPLE.—What force is required to overcome the force of gravity acting on a train weighing 100 tons on a gradient that rises 10 feet in every 500 feet?

SOLUTION.—Applying the formula just given,

$$F_w = 2{,}240 \times 100 \times \tfrac{1}{50} = 4{,}480 \text{ lb.} \quad \text{Ans.}$$

19. Producing a Given Acceleration.—The total force required to produce a given acceleration in a body is the sum of the forces required to overcome the tractive resistance and the gradient, if any, and the forces necessary to accelerate the motion of a moving body and to produce rotational acceleration.

EXAMPLE.—How much force is required to give a 180-ton train a velocity of 30 miles per hour in 22 seconds? The track has a gradient of 1 in 50, and there is a tractive resistance of 10 pounds to the ton.

SOLUTION.—To attain a velocity of 30 mi. per hr. in 22 sec., the train must have a rate of acceleration of $\frac{30}{22} = 1{\cdot}36$ mi. per hr. per sec. By formula **3,** Art. **16,** the force required to accelerate the motion of a body weighing 1 ton at a rate of 1·36 mi. per hr. per sec. is $102 \times 1{\cdot}36 = 138{\cdot}72$ lb. Therefore, to accelerate the movement of a 180-ton train, the force is $180 \times 138{\cdot}72 = 24{,}970$ lb., nearly. From Art. **17,** the rotational acceleration is one-tenth of this, or 2,497 lb. As the tractive resistance is 10 lb. per ton, for the entire train the total tractive resistance is $180 \times 10 = 1{,}800$ lb. From Art. **18,** the force required to overcome a gradient of 1 in 50 is $2{,}240 \times 180 \times \frac{1}{50} = 8{,}064$ lb. Therefore, the total force required to give the train the desired velocity is

$$24{,}970 + 2{,}497 + 1{,}800 + 8{,}064 = 37{,}331 \text{ lb.} \quad \text{Ans.}$$

20. Finding Acceleration From Total Force.—If the total force applied to a train is known, the accelerating force may be found by applying the following rules:

Rule.—I. *From the total force, deduct the forces necessary to overcome tractive resistance and the gradients, if any; the remainder is the combined accelerating force.*

II. *Divide the combined accelerating force by 1·1 to find the total translational accelerating force; dividing this by the weight of the train, in tons, gives the translational accelerating force, in pounds per ton.*

III. *Divide the translational accelerating force per ton by 70 to find the acceleration in feet per second per second, or divide by 102 to find the acceleration in miles per hour per second.*

EXAMPLE.—What acceleration will be produced if a total force of 37,331 pounds is applied to a 180-ton train, when the track has a gradient of 1 in 50 and there is a tractive resistance of 10 pounds per ton ?

SOLUTION.—For a 180-ton train, the force necessary to overcome a tractive resistance of 10 lb. per ton is $10 \times 180 = 1{,}800$ lb. To overcome a gradient of 1 in 50 requires a force of $2{,}240 \times 180 \times \frac{1}{50} = 8{,}064$ lb. Deducting the sum of these forces, 9,864 lb., from 37,331 lb. leaves 27,467 lb. as the combined accelerating force. The force required to accelerate the train is therefore $27{,}467 \div 1{\cdot}1 = 24{,}970$ lb., nearly, or $24{,}970 \div 180 = 138{\cdot}72$ lb. per ton. By formula **3**, Art. **16**, $P = 102\,f'$, and, transposing,

$$f' = \frac{P}{102} = \frac{138{\cdot}72}{102} = 1{\cdot}36 \text{ mi. per hr. per sec.} \quad \text{Ans.}$$

21. Limits to Acceleration.—The maximum acceleration in the speed of a train is limited by the maximum tractive force that can be applied. The maximum tractive force depends on the adhesion between the driving wheels and the rails, and therefore on the weight on the driving wheels and the roughness of the contact surfaces of wheels and rails. The maximum tractive force or adhesive force that can be obtained by the driving wheels may be found by multiplying the total weight on these wheels by a factor, called the **coefficient of adhesion**, which depends on the condition of the rails. The usual values for the coefficient of adhesion are given in Table II. If the rails are perfectly dry, a coefficient of $\frac{1}{4}$ may be used, and if the rails are wet and sanded slightly, a coefficient of $\frac{1}{5}$ or $\frac{1}{6}$ is obtainable. If the turning force applied to the wheels is greater than the adhesive force between the wheels and rails, the wheels will slip.

TABLE II
COEFFICIENT OF ADHESION

Condition of Rails	Values of Coefficient
Dry	$\frac{1}{4}$ to $\frac{1}{5}$
Clean wet	$\frac{1}{5}$ to $\frac{1}{6}$
Dirty wet	$\frac{1}{5}$ to $\frac{1}{7}$
Greasy	$\frac{1}{7}$ to $\frac{1}{9}$
Wet, strewn with sand	$\frac{1}{5}$ to $\frac{1}{6}$

22. Adhesion Under Braking Conditions.—The effectiveness of braking depends on the friction between the wheels and the brakes and between the wheels and the rails. The retardation produced by braking differs from acceleration in that the brakes are generally applied to most of the wheels of a train, whereas usually only a few wheels are used as driving wheels. With the usual coefficients of adhesion, if all wheels are braked, the corresponding maximum values of retardation are as given in Table III.

TABLE III
MAXIMUM VALUES OF RETARDATION

Coefficient of Adhesion	Feet Per Second Per Second
$\frac{1}{4}$	8·0
$\frac{1}{5}$	6·4
$\frac{1}{6}$	5·3
$\frac{1}{7}$	4·6
$\frac{1}{9}$	3·6

23. Acceleration of Steam Locomotives and Electric-Motor Coaches. On trains hauled by steam locomotives, the acceleration is usually very much lower than that which is commonly employed on electric trains. The acceleration of a steam train seldom exceeds 1·8 feet per second per second; on the Liverpool Overhead Electric Railway, an acceleration as much as 4·2 feet per second per second has been recorded.

EXAMPLE 1.—What is the maximum acceleration that can be applied to a train weighing 180 tons that is composed of a 50-ton steam locomotive and several coaches ? The weight on the driving wheels of the locomotive is 36 tons; the coefficient of adhesion, $\frac{1}{6}$; the tractive resistance, 10 pounds per ton; and the gradient, 1 in 50.

SOLUTION.—The maximum tractive force that can be applied to the train is $\frac{1}{6} \times 36 \times 2{,}240 = 13{,}440$ lb. As the force required to overcome tractive resistance is $10 \times 180 = 1{,}800$ lb., and the force required to overcome the gradient is $2{,}240 \times 180 \times \frac{1}{50} = 8{,}064$ lb., the combined accelerating force is $13{,}440 - (8{,}064 + 1{,}800) = 3{,}576$ lb. The translational accelerating force is $3{,}576 \div 1{\cdot}1 = 3{,}251$ lb., or $\frac{3{,}251}{180} = 18$ lb. per ton, nearly. This force, by formula **2**, Art. **16**, gives an acceleration of $\frac{18}{70} = {\cdot}257$ ft. per sec. per sec. Ans.

EXAMPLE 2.—What is the maximum acceleration that can be applied to a train weighing 180 tons, it being composed of four electric coaches that weigh 36 tons each and two coaches that weigh 18 tons each ? Each electric coach is equipped with four motors, one on each axle, and the other conditions remain as in example 1.

SOLUTION.—Since the entire weight of each electric coach is carried by driving wheels, the total weight available for adhesion is $4 \times 36 = 144$

tons. With a coefficient of adhesion of $\frac{1}{6}$, the maximum tractive force that can be applied to the train is $\frac{1}{6} \times 144 \times 2{,}240 = 53{,}760$ lb. Deducting from this the forces required to overcome the tractive resistance and the gradient (1,800 + 8,064) gives for the combined force of acceleration 53,760 − 9,864 = 43,896 lb. The translational accelerating force is 43,896 ÷ 1·1 = 39,905 lb., or $\frac{39{,}905}{180} = 222$ lb. per ton, nearly. This force, by formula **2**, Art. **16**, gives an acceleration of $\frac{222}{70} = 3{\cdot}17$ ft. per sec. per sec., which is nearly 12 times the acceleration of the steam locomotive.

CONTROL

MULTIPLE-UNIT SYSTEM

24. Necessity of Central Control.—A train consisting of a number of electric-motor coaches will accelerate faster than a train drawn by a locomotive, because of the multiplicity of driving axles and therefore of motors. But all these motors must be capable of being controlled from any motor coach, and the control must be suited to any number of coaches. Such trains are therefore equipped on the **multiple-unit system,** each train being made up of a number of units each complete in itself, but connected together electrically by means of control circuits. The control circuits are arranged so that electromagnetic switches on each coach may be operated simultaneously from one point, thus giving control of all the motors.

25. Advantages of Multiple-Unit Control.—Since it makes no difference to the speed or accelerating power of a train whether coaches are added or taken off, by the multiple-unit system trains may be made up to suit the requirements of the traffic without interfering with the ability of any train to maintain a high average speed. As the acceleration and average speeds are high, the same track and rolling stock can be made to produce more train miles each day. It is also possible to control the trains from either end, thus minimizing the shunting necessary at terminal stations when locomotives are used.

CHOICE OF MOTORS

26. Points Governing Choice. — When choosing the motors for any particular work, care must be taken that they have sufficient mechanical strength and will not overheat or spark; they should also be able to accelerate rapidly when going up steep gradients. The motors should be of standard sizes and must fit the space available between the track wheels. They should have maximum speeds on straight level track that will enable the train to keep schedule time, yet this speed should not be much in excess of that normally required. Their number,

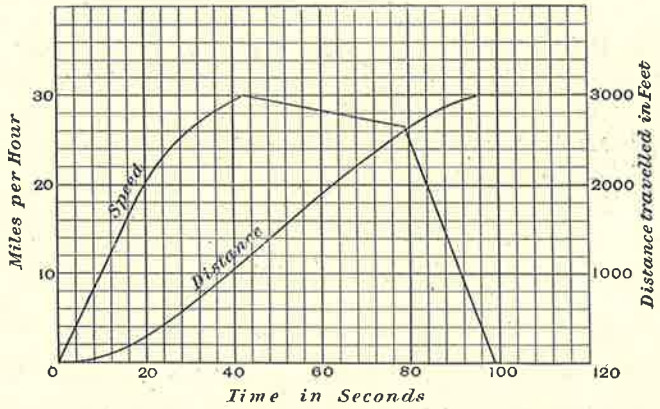

FIG. 4

size, and arrangement depend on the acceleration required and the weight of the trains.

27. Determination of an Average Cycle.—When a train is running between stations the speed varies at different points because of different conditions of track and grade, and also because of the acceleration at starting and the retardation at stopping. At some part of the run the speed usually reaches a more or less constant value. The actual values of the speed, as well as the relative lengths of time of accelerating, running at full speed, coasting, and braking will vary with each case. The cycle of operations for a special case is shown in Fig. 4. Starting from zero, the speed curve rises uniformly to 19·8 miles per

hour in 19·3 seconds; it then rises less rapidly until 30 miles per hour is reached at the end of 42 seconds. At this point the power is shut off and coasting begins, and the speed drops to 26·3 miles per hour at the end of 79 seconds, at which point the brakes are applied and the train is brought to rest in 99 seconds from the start. During this time the distance travelled has been 3,000 feet, or ·568 of a mile, as shown by the distance curve.

28. Probable Weight of Train.—To find the size of motors that will perform a certain cycle of operations in a certain time, it is first of all necessary to estimate the weight of the train. Corridor coaches for main-line railways weigh about 25 tons each and the dining cars about 35 tons, while the coaches used on urban electric railways to carry 48 passengers weigh about 20 tons without, and 30 tons with, motor equipment. Trailers, or coaches not equipped with motors, weigh about 16 tons each. The weight of the passengers is generally allowed for at the rate of 16 to the ton.

EXAMPLE.—Find the weight of an electric train that consists of two motor coaches and four trailers. The weight of each motor coach is 30 tons and the weight of each trailer is 16 tons.

SOLUTION.—Allowing 16 passengers to the ton, the weight of the passengers in each coach may be taken as $\frac{48}{16} = 3$ tons, and for the train $6 \times 3 = 18$ tons. The weight of the motor coaches is $2 \times 30 = 60$ tons; of the trailer $4 \times 16 = 64$ tons. The weight of the entire train is therefore

$$18 + 60 + 64 = 142 \text{ tons.} \quad \text{Ans.}$$

29. Maximum Horsepower of Motors.—Throughout the acceleration period of the cycle of operations, the pull exerted is at its maximum value, and the horsepower reaches its highest value at the end of this period.

Let P' = tractive force of motors, in pounds;
V = speed, in miles per hour.

Then, the maximum horsepower of the motors will be

$$\text{H.P.} = \frac{5{,}280\ P'\ V}{33{,}000 \times 60}$$

EXAMPLE.—What is (*a*) the maximum pull and (*b*) the horsepower of the motors, if a train weighing 142 tons reaches a speed of 19·8 miles per hour in 19·3 seconds? Assume that the tractive resistance is 10 pounds per ton.

SOLUTION.—(*a*) The pull required to accelerate at the rate of $\frac{19{\cdot}8}{19{\cdot}3}$ = 1·025 mi. per hr. per sec. is, from formula **3**, Art. **16**, $P = 102 \times 1{\cdot}025 = 104{\cdot}55$ lb. For 142 tons, the force is $142 \times 104{\cdot}55 = 14{,}846$ lb. The rotational acceleration is one-tenth of this, or $\frac{14{,}846}{10} = 1{,}485$ lb., nearly. The tractive resistance is $10 \times 142 = 1{,}420$ lb. Therefore, the maximum pull required for acceleration is

$$14{,}846 + 1{,}485 + 1{,}420 = 17{,}751 \text{ lb.} \quad \text{Ans.}$$

(*b*) Then, by the formula just given, the horsepower exerted by the motors will be

$$\frac{5{,}280 \times 17{,}751 \times 19{\cdot}8}{33{,}000 \times 60} = 937 \text{ H.P., nearly.} \quad \text{Ans.}$$

ENERGY CONSUMPTION

30. Performance Curves.—When a motor has been chosen, its energy consumption may be determined by means of **performance curves.** The base line of the curves, shown in Fig. 5, gives the current required, in amperes; the left-hand margin

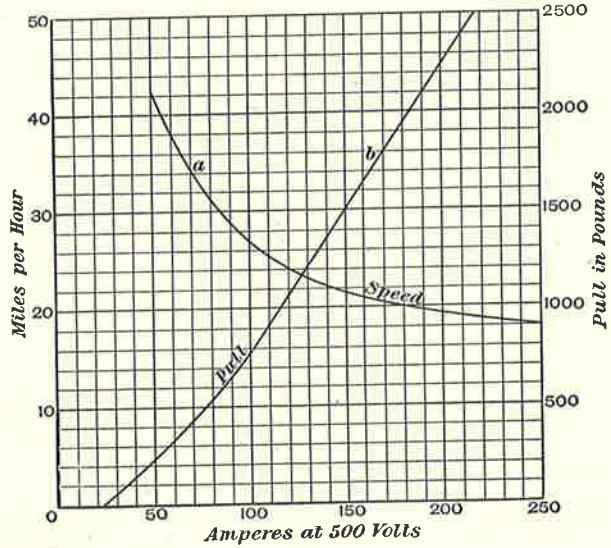

FIG. 5

V. 22—416—35

gives the speed, in miles per hour; and the right-hand margin gives the pull, in pounds. Curve *a* shows the relation between speed and current; for example, when the current is 150 amperes, at 500 volts pressure, the speed is 21·5 miles per hour. Curve *b* shows the relation between the tractive effort, or pull, in pounds, and the current taken by the motors. When the current is 150 amperes the pull is shown to be 1,500 pounds.

31. Variation of Current During Acceleration.—The variations of current during switching on are of the same character as those which occur with tramcar controllers. If a car or train is started from rest and allowed to accelerate at the maximum rate as shown by the speed curve, Fig. 6, the current required will vary greatly. For the case shown, the motors are connected two in series during the first 9 seconds, and the resistance is cut out step by step; the subsequent 10·3 seconds represents the second stage of the switching, when the motors are connected in parallel with each other, a resistance being in series with them, and the resistance is again cut out step by step. Owing to these variations of current, the maximum current is much greater than the average. Therefore, when a calculation is made for the horsepower exerted by a train during a given cycle, the figure arrived at is the average value. For instance, the 937 horsepower found in the example in Art. **29** is the average value, and the maximum may be as high as 1,100 horsepower. These momentary values of the current or of horsepower are of no great importance in the consideration of the energy consumption, but they are of great importance when the limit of adhesion is considered, and when the supply of current to the train is taken into account, because they affect the size of the generating plant, the feeder, and the distribution systems.

32. Period of Switching.—The current curve, Fig. 6, shows that for the first 9 seconds, with the motors in series, the current is steady at 740 amperes. Then it jumps to 1,480 amperes, with the motors in parallel, where it remains for 10·3 seconds; for the next 23·2 seconds it drops, quite rapidly at first, until it reaches a value of 685 amperes, at which point the current is cut off. The speed curve shows that the motors accelerated

at a uniform rate until the current taken began to fall from 1,480 amperes, at which time the train had a speed of 19·8 miles per hour. The train then accelerated more slowly until it reached the speed of 30 miles per hour at the end of 42·5 seconds, when

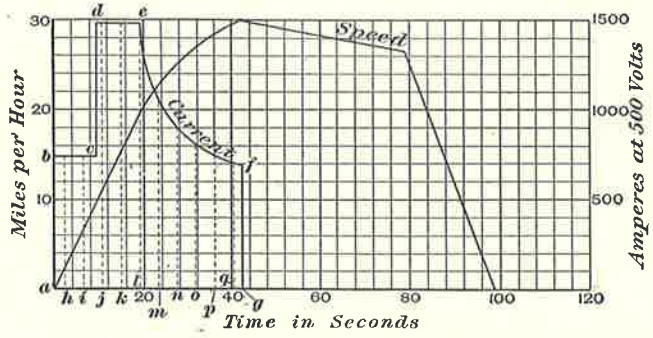

Fig. 6

the current was cut off. The train then coasted along by its own momentum for 37 seconds, when the brakes were applied. This, however, is a modified curve, for the means used to control or

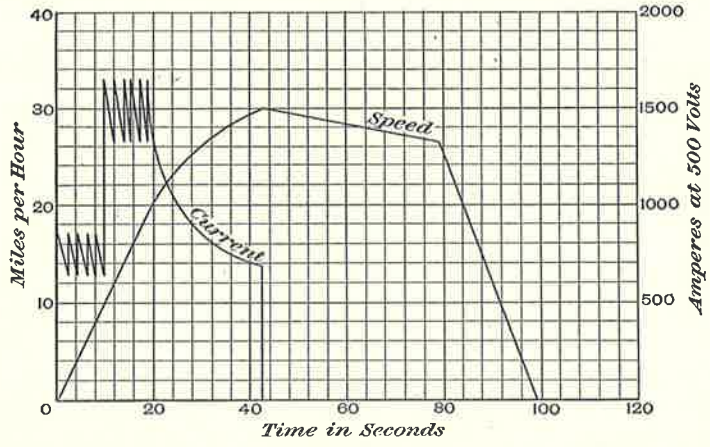

Fig. 7

regulate the motors cannot maintain the current at the constant values shown during the first 19·3 seconds. During this time, which is known as the **period of switching**, the current varies somewhat, as shown in Fig. 7. When any section of resistance

is cut out, the current rises quickly and then gradually drops as the speed increases.

33. Watt-Hours Per Ton-Mile.—The calculation of the energy consumption may be arrived at by finding the area included between the base line and the current curve *a b c d e f g* in Fig. 6. This can be done by dividing the area into 10 equal parts and measuring the height of each as shown by the lines *h, i, j, k, l, m, n, o, p, q*. Adding these heights together and dividing by 10 gives the average height of the area *a b c d e f g*, and reading this off on the right-hand scale gives 1,000 amperes. The distance from *a* to *g*, as read on the bottom scale, is 42·5 seconds, so that the area *a b c d e f g* represents 42,500 ampere-seconds.

Assume that the curve, Fig. 7, gives the results for a train weighing 142 tons, which during each cycle covers a distance of 3,000 feet, or ·568 mile. The usual voltage of supply is 500, therefore the total electric energy supplied to the train during each cycle is $500 \times 42{,}500$ watt-seconds, or $\frac{500 \times 42{,}500}{60 \times 60}$ = 5,903 watt-hours, nearly. Therefore, the energy consumption expressed in watt-hours per ton-mile is $\frac{5{,}903}{142 \times \cdot 568} = 73$, nearly.

34. Cost of Energy for a Given Train Service.—In steam-railway practice, it is customary to reckon in train-miles, and the energy or fuel consumption, etc., are given at so much per train-mile. As there is usually one locomotive to each train, it is practically the same as saying per locomotive mile. In electric-railway practice, the trains are usually made up of motor coaches and trailers, and the numbers of these to a train can be varied quite easily to suit traffic conditions throughout the day and at various seasons of the year. It is therefore much more correct and convenient to express the energy, or fuel consumption, at so much per ton-mile. Knowing, or assuming, the amount of energy required in watt-hours per ton-mile, as well as the cost per kilowatt-hour at the power house, it is possible to estimate quite closely the cost of energy that may be required for the operation of any particular railway.

EXAMPLE.—What is the daily cost of energy for running trains on a railway that has a daily train-mileage of 3,600, if one half the trains weigh 150 tons and the other half 80 tons? The energy consumption is 65 watt-hours per ton-mile, and the cost of energy is ·5d. per kilowatt-hour.

SOLUTION.—The ton-mileage of the railway is $\left(150 \times \frac{3{,}600}{2}\right) + \left(80 \times \frac{3{,}600}{2}\right)$ = 414,000. The consumption of energy is, therefore, 414,000 × 65 = 26,910,000 watt-hr., or nearly 27,000 K.W.-hr. At ·5d. per K.W.-hr., the daily cost for energy is

$$\frac{\cdot 5 \times 27{,}000}{240} = £56, \text{ nearly.} \quad \text{Ans.}$$

35. Factors Varying the Amount of Energy.—The consumption of energy depends on many factors. For example, a careless application of the current to the motors may greatly increase the consumption; some trains take 50 per cent. more than others from this cause. Gradients, too, increase the consumption, especially if there is any starting of the train when mounting the grade. Signal checks or stops due to irregular working of the traffic are other causes of additional energy consumption. The consumption of energy on one underground railway in London is increased 15 per cent. by this cause, while on an interurban railway it does not exceed 8 per cent. Some tube railways, as the Central London Railway, are constructed with each station at the top of a gradient; this plan results in a saving of energy that is not obtained when the track is level. There are also the losses in feeders, which may amount to 5 per cent.; if there is a long transmission line, the losses on that may be another 10 per cent.

36. Relation of Acceleration and Kinetic Energy.—If a train accelerates rapidly, it is possible to switch off the power some time before the brakes are applied and a part of the kinetic energy is used in overcoming the tractive resistance. In this way it is possible to reduce the total energy expended by making the stored energy do useful work. The speed curves *a* and *b*, Fig. 8, show that power is supplied in the first case for 40 seconds only, and in the second case the power supply is continued for 72 seconds. In both cases the trains, each weighing 150 tons, are to start, travel ½ mile, and stop, in 90 seconds. Curve *a*

shows the speed of one train, which at the start has an acceleration of 2 feet per second per second, and reaches its maximum speed of 27·5 miles per hour in 40 seconds, then coasts for 40 seconds, or until the speed has dropped to 22·1 miles per hour, before the brakes are applied. Curve *b* shows the speed of the other train, which at first accelerated at the rate of 1·2 feet per second per second, and reached its maximum speed of 31·2 miles per hour in 72 seconds, just at the time the brakes

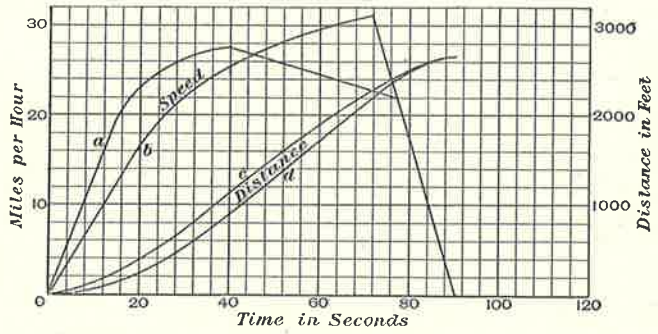

FIG. 8

had to be applied. Curves *c* and *d* are the respective distance curves.

Let W = weight of train, in pounds ;
V = speed of train, in feet per second ;
g = acceleration due to gravity, taken as 32·2.

Then, for a train,

$$\text{the kinetic energy in foot-pounds} = \frac{W V^2}{2g}$$

As 22·1 miles per hour is $\frac{22{\cdot}1 \times 5{,}280}{60 \times 60} = 32{\cdot}4$ feet per second, very nearly, the train having the speed shown by curve *a*, at the instant the brakes are applied, has a kinetic energy of $\frac{150 \times 2{,}240 \times 32{\cdot}4^2}{2 \times 32{\cdot}2} = 5{,}477{,}000$ foot-pounds, approximately.

A speed of 31·2 miles per hour is $\frac{31{\cdot}2 \times 5{,}280}{60 \times 60} = 45{\cdot}8$ feet per second ; therefore, the train having the speed shown by curve *b* has, at the instant the brakes are applied, a kinetic energy of $\frac{150 \times 2{,}240 \times 45{\cdot}8^2}{2 \times 32{\cdot}2} = 10{,}944{,}200$ foot-pounds, approximately.

37. Use of Brakes in Stopping.—The kinetic energy due to the speed of a train at the time the brakes are applied must be dissipated mostly as heat which is developed by the friction between the wheels and the brake blocks. The greater the amount of kinetic energy, the greater the wear on both brake blocks and wheels, and also the greater the total amount of energy supplied. Considered from the standpoint of economy of power, it would be advisable to allow a train to come to a standstill without applying the brakes. This plan of stopping trains is not adopted because of the loss in time due to low retardation. By the use of brakes for stopping, the number of train-miles in a given time can be increased, and therefore the earning capacity of the train may be increased.

In the preceding article it is shown that the kinetic energy of a train moving at a speed of 31·2 miles per hour is nearly double the kinetic energy of a train moving at a speed of 22·1 miles per hour. The wear on the brake blocks is much greater in the first case than in the second.

38. Effect of High Acceleration on Motors and Plant.—High acceleration of trains gives economy in energy consumption, provided the kinetic energy is partly used in overcoming tractive resistance before the brakes are applied for stopping the train, but larger motors are required than for low acceleration. The large motors place more weight on the driving wheels ; they also make a greater maximum demand on the generating station, and this necessitates a larger and more expensive generating plant and more expensive feeder and distribution systems. The most favourable acceleration for any one case can only be determined by carefully working out the calculations on different assumptions, and considering the advantages and disadvantages of each result.

39. Examples of Energy Consumption.—When the Liverpool Overhead Railway was first equipped the acceleration of the trains

was 1·6 feet per second per second, whereas now it is 4·2 feet per second per second with a consumption of 137 watt-hours per ton-mile.

On the Central London Railway the energy consumption is very low, being about 44 watt-hours per ton-mile, which result is obtained chiefly by means of the special arrangement of gradients. At starting, a down gradient assists the motors; and on approaching a station, the train is retarded by an up gradient and brakes combined. In this way, the energy absorbed in the brakes is reduced. The stations are about $\frac{1}{2}$ mile apart, and the mean speed, including stops, is about $15\frac{1}{2}$ miles per hour. For the Inner Circle line of the London Metropolitan Railway the manufacturers' guarantees were between 65 and 75 watt-hours per ton-mile. The average distance between stations is $\frac{1}{2}$ mile, and the mean speed, including stops, about 16 miles per hour.

40. To Find Horsepower of a Locomotive.—There is usually no precise information as to the duty required from an industrial locomotive. In most cases it is required to haul a number of wagons or tubs, and assumptions must be made as to their number and weight. The ordinary 10-ton coal truck weighs 5 or 6 tons. Goods wagons are much heavier, while coal tubs straight from the collieries are lighter. In some cases the latter weigh only 13 hundredweights when fully loaded. An acceleration of approximately ·5 foot per second per second is generally considered sufficient. Having obtained all data available and made assumptions from them, a figure for the pull at a given speed on the level is arrived at; a pull of 5 tons at a speed of 10 miles per hour may be allowed for an industrial locomotive.

EXAMPLE.—What size motor equipment is required for a locomotive which is to exert a pull on the level of 11,200 pounds at a speed of 10 miles per hour? The tractive resistance is 10 pounds per ton and the adhesion coefficient is $\frac{1}{7}$.

SOLUTION.—If W is the weight of the locomotive, in tons, the force required to keep the locomotive running at 10 mi. per hr., allowing a tractive resistance of 10 lb. per ton, is 10 W lb. Adding to this the pull which the locomotive must exert, namely, 11,200 lb., the total pull given by the motors must be $11{,}200 + 10\ W$ lb. Allowing for an adhesion coefficient of $\frac{1}{7}$, the weight of the locomotive is $W = 7 \times \frac{(11{,}200 + 10\ W)}{2{,}240}$ tons. $W = \frac{78{,}400 + 70\ W}{2{,}240}$, or $2{,}240\ W = 78{,}400 + 70\ W$; $2{,}170\ W = 78{,}400$, and $W = \frac{78{,}400}{2{,}170} = 36{\cdot}1$ tons, nearly. The total pull, therefore, that must be exerted by the motors will be $11{,}200 + 36{\cdot}2 \times 10 = 11{,}562$ lb. This pull at a speed of 10 mi. per hr. is equivalent to an output of

$$\frac{11{,}562 \times 10 \times 5{,}280}{33{,}000 \times 60} = 308 \text{ H.P., nearly.} \quad \text{Ans.}$$

41. Limit of Weight on Axle.—A maximum weight of 18 tons on each axle may be assumed for a first-class main-line railway on which the track and the bridges are very strongly built. The latest steam locomotives of the Great Western and Midland Railways have a maximum weight on axles of about $19\frac{1}{2}$ tons. On electric locomotives, and particularly on motor coaches, it is so easy to distribute the load over several motors that the maximum weight on the axle need never exceed 12 tons. This means cheaper tracks, bridges, etc. In addition, as the motion of electric motors is purely rotary, the wear and tear on the rails and wheels is less and the adhesion between them is greater for a given weight on the axles than with steam locomotives. The reciprocating engines of the latter with various unbalanced parts give a hammer blow which is very destructive to the rails. When dividing up the maximum power required to haul a given train, it should be noted that the number of motors must be even, so that they may be connected in series and in parallel. Four or eight motors is the most usual practice.

42. Necessity for Adequate Sanding.—For ordinary passenger traffic carried in motor coaches and trailers, the necessity for using sand only occurs occasionally, as when starting on greasy rails. With electric locomotives there are usually fewer driving axles and so more sand may be required, especially when hauling heavy loads up gradients. When providing sanding arrangements, the climatic conditions of the country where the locomotive is going to work must be considered. For example, in a moist climate like that of Great Britain the necessity for sanding is greater than in drier and warmer countries.

ENERGY SUPPLY

METHODS OF COLLECTING CURRENT

43. Overhead Conductors and Conductor Rails. — There are two methods of conveying current to electric trains: by means of copper overhead conductors, and by means of steel-rail conductors laid along the track. They are usually called the **overhead-wire system** and the **third-rail system.** The overhead wire is usually employed for interurban railways and light-weight locomotives, and the third rail is employed for urban and suburban railways. The overhead system is practically identical with that used for tramways, being modified where necessary for a high-speed service of trains. In the case of industrial railways, it is simplified by the use of wooden poles, etc. On tramway systems, the highest voltage permitted by the Board of Trade is 550 volts; but as there is usually no such restriction on railways, it is possible to use 1,000 volts or higher. This, of course, necessitates better insulation.

44. Third and Fourth Rails.—The third rail is usually of steel of higher conductivity than the track rails, and it is supported on insulators. Contact shoes attached to the locomotive or the motor coaches slide along the rail as the train moves forwards, and the current which is picked up passes through flexible cables to the wiring of the car, thence through the fuses, controllers, resistances, etc., to the motors. In some cases, the return current passes back to the generating station or substation by means of the track rails; in other cases, it returns through a second conductor rail, which is usually called the **fourth rail.** Where both third and fourth rails are used, as in the case of the Metropolitan, the Metropolitan District, and the Mersey Tunnel lines, the positive, or third, rail is outside and about 18 inches from the track rail, while the negative rail is laid along the sleepers midway between the track rails.

45. Calculations for Overhead Wires.—Many of the calculations for overhead wires are similar to those for tramways,

but the current is usually heavier and there is a less frequent service. For example, in almost all tramway systems a number of cars are at work simultaneously; whereas, in railways where an overhead wire is used, it frequently happens that not more than one or two trains are taking current at the same time. In tramway work, it is usual to design the overhead line and feeder system so that the drop of volts between the power station and the cars, under the worst conditions, will not exceed a certain amount, often 15 per cent. In a small railway, operating at most two trains, there are great fluctuations in the load, so that it is wise to limit this voltage drop to a smaller value, for instance, 10 per cent.

46. Voltage Drop in Wires and Rails.—Take the case of a locomotive which must run over a line 2 miles in length, hauling a load in both directions. In one direction it works against a gradient of 1 in 20, and in the other it works with the gradient. The power station is at the end of the line, that is, at the top of the gradient. The locomotive requires for starting a current of 160 amperes, and for running up the gradient a current of 120 amperes. The overhead line consists of two trolley wires, each No. 0000 S.W.G. hard copper having a resistance of ·337 ohm per mile. As the two trolley wires are in parallel their combined resistance will be $\frac{\cdot 337}{2}$ ohm per mile. Then the volts drop on the line will be $160 \times 2 \times \frac{\cdot 337}{2} = 54$ volts, nearly, at starting at the bottom of the gradient, which is about 10 per cent., and $120 \times 2 \times \frac{\cdot 337}{2} = 40{\cdot}4$, or 40 volts, nearly, when running up the gradient.

A fair allowance for the drop in the track rails is 10 volts with 160 amperes, and 7·5 volts with 120 amperes, so that the total drops will be 64 and 47·5 volts. The generating station supplies current to the overhead line at 550 volts, and therefore the voltage at the locomotive every time it starts will be $550 - 64 = 486$ volts, and when it begins to climb the gradient $550 - 47{\cdot}5 = 502{\cdot}5$ volts.

47. Advantage of High Voltage.—Suppose that, in the example given in Art. **46**, instead of using a 550-volt supply, the generating station gives 1,100 volts. The current required by the locomotive will be 80 amperes for starting and 60 amperes for climbing the gradient, as the power is the same as before. If the drop is the same percentage of the supply voltage as before, namely, about 10 per cent., then, with the same No. 0000 S.W.G. wires, the current can be transmitted 8 miles instead of 2 miles. This can be expressed in general terms as follows: *With a given per cent. loss, the distance over which any given power can be transmitted varies as the square of the voltage of transmission.*

Of course, the voltage is limited to that for which it is possible to build the motors. By the use of commutating poles and extra-quality insulation, it is now possible to build traction-motors of large size for 1,000 or 1,200 volts. If two such motors are connected permanently in series and treated as a single unit, the voltage of the overhead wire may be 2,000 or 2,400 volts.

48. Calculations for Third Rail.—Hard-steel track-rails have a resistance about 11 to 13 times that of copper of similar cross-section. On the other hand, rails can be made of nearly pure iron at a reasonable price and have a resistance only about 7 times that of copper. The conductor rails of the London underground railways have a resistance 6·4 times that of copper of similar cross-section. These rails contain ·05 per cent. of carbon, ·019 per cent. of manganese, ·054 per cent. of phosphorus, ·059 per cent. of silicon, and ·03 per cent. of sulphur. Ordinary track-rail steel usually contains about ·4 per cent. of carbon and ·85 per cent. of manganese.

As a copper conductor 1 square inch in area has a resistance of ·042 ohm per mile, an iron conductor rail weighing 50 pounds per yard and measuring 5 square inches in cross-section will have a resistance of $\frac{\cdot 042}{5} \times 7 = \cdot 0588$ ohm per mile. Similarly, a conductor rail weighing 100 pounds per yard has a resistance of ·0294 ohm per mile, and will carry a current of 1,000 amperes with a drop of $1{,}000 \times \cdot 0294 = 29 \cdot 4$ volts per mile.

49. Distance Between Substations.—On the Metropolitan District Railway of London, the distance from substation to substation along the line varies from one to several miles. On the busiest section, from Earl's Court to Mansion House, the distances between substations are 1, 1·4, 1·35, and 1·3 miles. On the route of the Central London Railway, which is $6\frac{1}{4}$ miles long, there are three substations. The voltage of supply is usually 600, and the drop is generally taken at about 10 per cent., or 60 volts, half of which is in the positive or third rail.

EXAMPLE.—A train requires 1,800 amperes when it is midway between two substations; the third rail weighs 100 pounds per yard and has a resistance of ·0294 ohm per mile. Allowing for a drop of 30 volts on the third rail between each substation and the train, what should be the distance apart of the substations?

SOLUTION.—Each substation will deliver 900 amperes, and as the resistance of a 100-lb. conductor rail is ·0294 ohm per mi., the drop per mi. is $900 \times \cdot 0294 = 26 \cdot 46$ volts. Therefore, the distance apart of the substations must be $\frac{2 \times 30}{26 \cdot 46} = 2\frac{1}{4}$ mi., nearly. Ans.

50. Need of a Fourth Rail.—Board of Trade regulations demand that when tramway rails form part of the electric circuit the potential difference between any two points of this uninsulated return must not exceed 7 volts. Although it is not always necessary for electric railways to comply with this regulation, it is generally done when electrolysis may injure property. When there are few, if any, water or gas pipes, as in the open country, there is no objection to the use of the track rails for carrying the return current, even if the drop is 20 or 30 volts, especially as wooden sleepers help to insulate the track rails from earth. On the other hand, for a heavy railway in a large city, such as London, it is not advisable to allow such a drop on the track rails. The question then arises, Is it better to use track rails and employ whatever means are necessary to reduce the drop to something less than 7 volts, or should an insulated return conductor rail be used? The answer depends on circumstances, more particularly on what means are necessary to reduce the drop to within the specified limit. On the Central

London Railway no special precautions need be taken, for the actual drop in the rails does not exceed 4 volts. On the Metropolitan District Railway of London, if the track rails were used without any auxiliary means for reducing voltage, the drop would be 30 volts. This railway has, however, a separate insulated fourth rail.

TRACK

SAFETY IN WORKING

51. Feeder Systems. — The proper arrangement of feeder systems for electric railways must be considered for each particular case from the following points of view: (*a*) Minimum disturbance of traffic in case of any failure of feeders, distribution conductors, etc.; (*b*) most convenient organization for controlling the feeder system; (*c*) precautions against danger to railway employees. In an extensive railway system in which there are several lines or branches, it would be a very serious drawback to electrification if all parts of the system were put out of operation when a fault occurred at one point. Of course, a complete breakdown of the power house might cause a stoppage of the entire system, but the chances of this are very remote, for modern power houses are equipped with several separate and complete generating units. Also, storage batteries are frequently installed in substations for direct-current railways. Besides, there is a tendency for electric-supply systems to help each other in cases of emergency. By dividing the feeder system into a sufficient number of sections, each of which can be isolated from the others, a short circuit or other failure on any one of them can be dealt with, so that other parts of the system are not affected. This dividing up of the feeder system into sections is called **sectionalizing**.

52. Control From Substations.—In an electric tramway the control is usually centred in the generating station, from which separate direct-current feeders are taken to the various parts of the tramway system. If the electric railway does not differ greatly from a tramway, the same method is applicable; but most electric railways do differ widely from tramways. A usual method is to distribute current from a number of substations which are supplied from a single power house, with high-tension alternating current. In this case the control must be divided, since the current supplied to the trains is not distributed from a single central point. Each substation, by means of its switchgear, has control of a certain portion of the railway, while the supply to the substations is controlled at the power house. Of course, all the substations are in telephonic communication with the power house.

53. Protection of Employees.—Means must be taken to protect those working on the line. It is not sufficient to provide

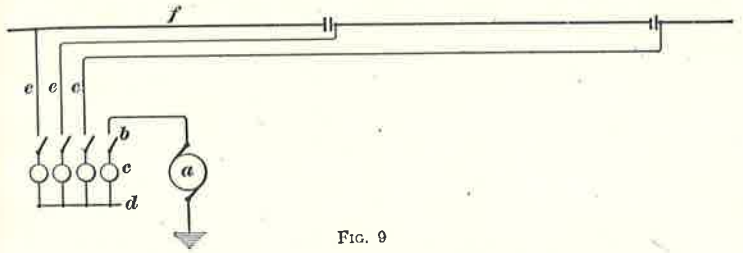

FIG. 9

for sectionalizing the line unless provision is also made so that two neighbouring sections cannot be connected together by a passing train. Suppose, for example, that a fault has occurred on a certain section, and that the section has been isolated by means of switches controlling the supply of current to it. If while men are working on this section a train closes the connection between this section and a neighbouring one which is alive, the result will be disastrous to the repairing gang. The simplest method of providing the necessary protection is to insert between any two sections a special length of conductor called a *train section*, which may be disconnected from the other sections.

54. Sectionalizing Feeder Systems. — In Fig. 9 is shown a simple arrangement for sectionalizing the feeders of a railway. The generator *a* is connected through an automatic circuit-breaker *b* and ammeter *c* to a bus-bar *d*; from this bus-bar

three feeders *e* are taken to three sections of the overhead line *f*, each feeder being provided with an ammeter and automatic circuit-breaker. By opening any one circuit-breaker the corresponding section of overhead line can be disconnected from the generator.

This arrangement is sufficient for the case in which the electric train or electric locomotive obtains current from the overhead line by means of a single collector. However, the train or locomotive may be fitted, as in Fig. 10, with two overhead collectors *a*, which are separated sufficiently to bridge the section insulators *b*. Then, if the section of overhead line to the right of the section insulator *a* is under repair and the locomotive gets into the position shown, current will pass from the live

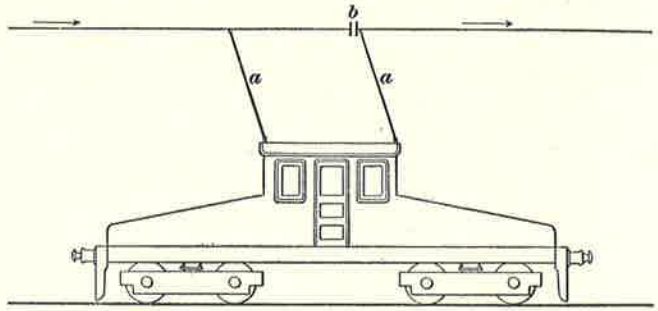

FIG. 10

section on the left through the collectors on the locomotive to the section under repair along the path indicated by the arrows.

55. Train Sections.—A **train section** is that part of the supply conductor between two insulators *a*, *a*, Fig. 11, which are so far apart that the collectors of a train or locomotive cannot bridge across the section between the insulators. One of these insulators is provided with a bridging switch *b*, which is normally kept closed, so that the train section forms part of one of the ordinary sections. When the supply is cut off from any section by means of the feeder switch in the generating station, the foreman in charge of the repairing gang must open the bridging switch, or *train-section switch*, and be responsible for keeping it open, until the work is completed. If an electric

train has a motor coach at each end and trailer cars between, then, if each motor coach has two collectors, the state of affairs shown in Fig. 12 is quite possible. As shown, the train section *a* is bridged by the four collectors, and current will flow in the direction indicated by the arrows. It is thus evident that complete protection can only be provided if the train section is

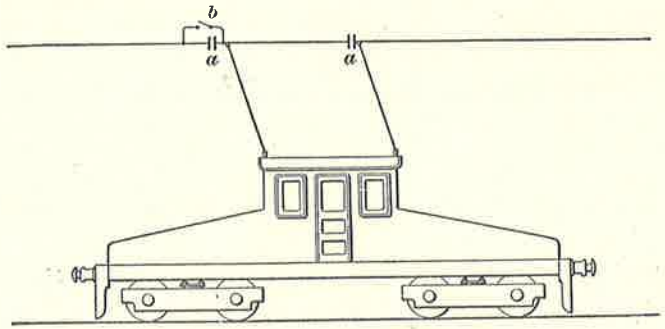

FIG. 11

longer than the greatest distance between the front and rear collectors on a single train.

56. Sectionalization of Third Rail.—Third-rail or third-and-fourth-rail systems supplied from a number of substations may be sectionalized in one of two ways: either each substation may have entire control over one section, or each section may be

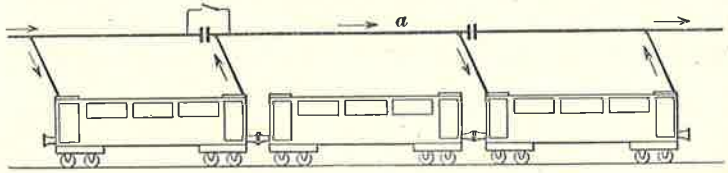

FIG. 12

under the control of two adjacent substations. The first method is shown in Fig. 13, where *a* is the rotary or generator, which is connected to the third rail *b* through the ammeter *c* and automatic switch *d*. The train sections *e* are connected to the conductor by the bridging switches *f*. In this system, the train sections are approximately midway between substations, and the substation attendants have no control over them; therefore,

when any work is to be done, the foreman of the repairing gang must open the bridging switches. The second method is shown in Fig. 14, where the generator, or rotary, *a* is connected to the third rail *b* through the automatic switch *d*, ammeter *c*, bus-bars *e*, and feeders *f*. The train sections *g* are connected direct

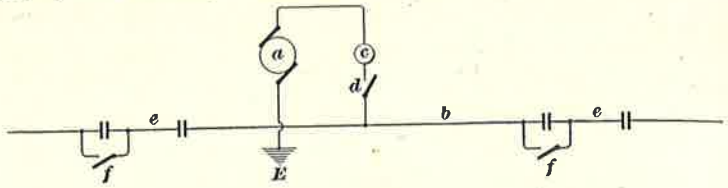

FIG. 13

to the substation bus-bars and are controlled by the substation attendants.

Apart from this difference, the main distinction between these two methods is an electric one. The second method has the

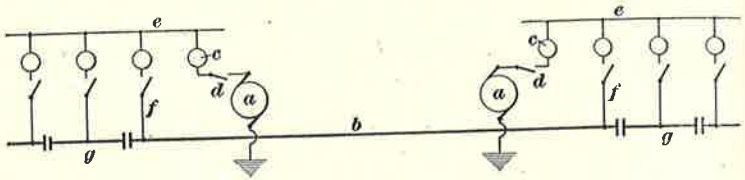

FIG. 14

advantage over the first in that current is supplied to each section simultaneously from both ends instead of from a single point at its centre. Assuming a train requires 2,000 amperes, then, by the arrangement shown in Fig. 15, the supply conductor has to

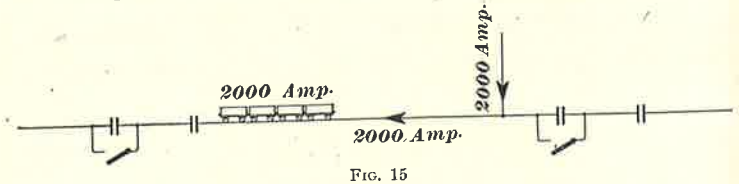

FIG. 15

carry the full current, while, with the arrangement shown in Fig. 16, each supply conductor or feeder carries only half the total current required by the train. Therefore, the conductors required in the latter case will have only half the cross-section required in the other.

The figures shown have been prepared for the third-rail system only, but the same principles apply to the third-and-fourth-rail system, except that both conductor rails must be section-alized in the same way, and positive and negative feeders and circuit-breakers must be provided.

57. Junctions and Cross-Overs.—The question of sectional-ization has been considered solely as if the line were continuous and without branches, junctions, and cross-overs. Apart from

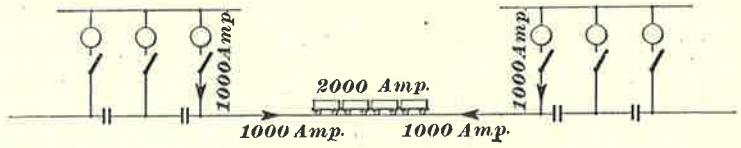

FIG. 16

the considerations introduced by the location of the substations, the design of the feeder system must be examined in the light of the arrangement of the track. The introduction of section insulators or their equivalents has for its principal object the minimizing of the disturbance of traffic consequent on a break-down on one part of the system, and where there are junctions or cross-overs, special sections must be provided; however, there can be no advantage in providing a degree of sectionalization that cannot be actually utilized in case of necessity.

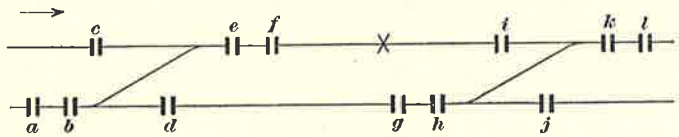

FIG. 17

58. Layout of Cross-Over.—A diagram showing the arrange-ment of the section insulators in the conductor rails at a double cross-over is given in Fig. 17. The insulators in the main rails are shown at *a*, *b*, *c*, *j*, *k*, *l*, and the insulators in the portion between the cross-over sections are shown at *d*, *e*, *f*, *g*, *h*, *i*. The insulators *b*, *e*, *h*, *k* must be placed at such a distance from the points of the cross-over roads that a train can run beyond the points and still have current to run back over the cross-over. Thus, supposing there is a derailment at the point × so that

the conductor rails are short-circuited, the section insulators at *e*, *f*, and *i* should be opened. Then, a train coming in the direction of the arrow will stop between the points of the cross-over road and the section insulator *e*, back up over the cross-over, and proceed on the other line to the next cross-over, where it will return to its own line. In this way single-line working is provided past the obstruction and the disturbance of traffic is minimized as far as possible. Junctions are treated in the same way; namely, the whole of a junction is isolated

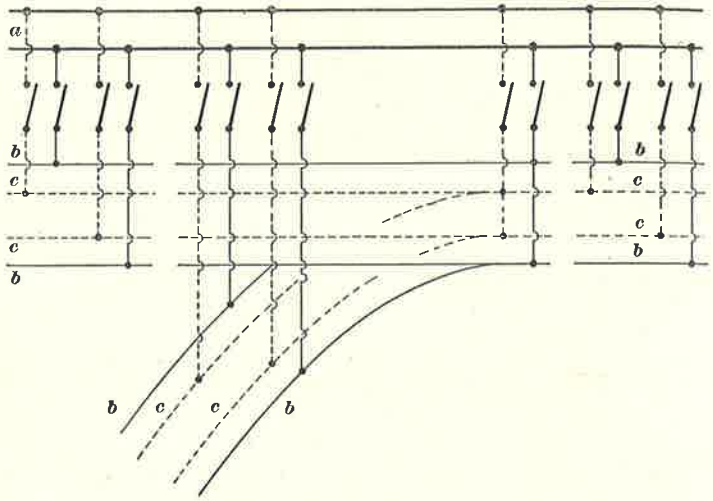

FIG. 18

from the adjacent parts. This isolation is shown in Fig. 18, by the openings in the third and fourth rails *b*, *c*. Switches connect or disconnect the bus-bars *a* from the conductor rails *b* and *c*.

ELECTRIFICATION OF RAILWAYS

COMPARATIVE COST OF STEAM AND ELECTRIC TRACTION

59. Reasons for Electrification.—In some cases, special circumstances, such as the smoke nuisance and ventilation of underground railways and tunnels, have practically forced railway

companies to adopt electric traction; for example, the London underground railways, the Mersey Tunnel Railway, and many long tunnels in the United States. But, as a rule, in the absence of such conditions, there must be some adequate financial inducement before any railway company will seriously consider the question of electrification, for the change from steam to electricity involves a considerable outlay of capital. The most obvious advantage that can be suggested for urban and suburban railways is the possibility of a large increase in the working capacity and the revenue-earning capacity, due to increased acceleration.

TABLE IV

RESULTS OF ELECTRIFICATION

Items	Mersey Tunnel Railway		North Eastern Railway	
	Steam	Electric	Steam	Electric
Passengers carried, exclusive of season-ticket holders . .	2,844,700	4,153,777	2,844,000	3,548,000
Gross receipts . . .	£29,470	£37,358	£129,000	£151,000
Working expenses .	£28,082	£32,442	£42,761	£47,779
Train-mileage . . .	155,039	401,046		

60. Results of Electrification.—In Table IV are given the results of electrifying the Mersey Tunnel Railway and the Tyneside lines of the North Eastern Railway. In the case of the Mersey Tunnel Railway, the figures are for 6 months only; in the other case they are given for a year, with the exception of the passengers carried, which are only for 6 months. The running cost, per train-mile, of the North Eastern Railway before electrification was 1s. $2\frac{1}{2}$d.; afterwards it was $6\frac{3}{4}$d.

61. Comparative Working Expenses.—In order to arrive at a clear understanding of the financial aspect of the electrification problem, it is necessary to study the comparison as to working expenses between steam and electric operation. The chief department of a railway which is affected by electrification is that

which deals with haulage, namely, the locomotive department; therefore, if any saving is to be shown, it must be in the expenses incurred in that department. In other respects the cost of working is not much altered, as, for example, traffic organization, permanent way, and signalling. With the third-rail system there is a little more for the permanent-way men to attend to, but, on the other hand, the station attendants, by being more regularly employed throughout the day, can handle much more luggage, and get the passengers on board and the trains away expeditiously. Further, the time taken in lighting up, banking fires, taking in fuel and water, etc., with steam locomotives, is saved with electric traction.

62. Cost of Fuel With Steam Locomotive.—The largest item of the working expenses of steam locomotives is the cost of fuel. The locomotive is by no means as economical a power producer as a generating station. An ordinary passenger locomotive usually requires about 3·5 pounds of coal to produce 1 indicated horsepower-hour, whereas a generating station requires anything from 2 pounds downwards. As the average cost per ton for locomotive coal in Great Britain, including delivery, is 16s., 3·5 pounds will cost ·3d. This corresponds, approximately, to ·35d. per brake horsepower-hour. If to this is added ·04d. for water, which includes all the costs incurred in water columns, pumping stations, etc., the total for fuel and water amounts to about ·39d. per brake horsepower-hour.

63. Cost of Electric Energy. — If electricity is used, the efficiency of transmission and the efficiency of the motors, etc., must be taken into account, and these vary a great deal. The efficiency of transmission may be anything from 80 per cent. with substations and conductor rails, to 90 per cent. without substations. The efficiency of motors, etc., may be taken as between 75 per cent. and 85 per cent., according as to whether there is much or little rheostatic loss. Taking as average figures 85 per cent and 80 per cent., respectively, the combined efficiency is ·85 × 80 per cent. = 68 per cent. A railway company could not purchase electrical energy in Great Britain on a fairly large scale for much less than ·5d. per kilowatt-hour. This is on the

assumption that there is a separate source of supply available, from which the railway could purchase electricity in the same way as they purchase coal. With the combined efficiency of 68 per cent., 1 brake horsepower-hour will be equivalent to $\frac{746}{\cdot 68 \times 1{,}000}$ = 1·1 kilowatt-hours. The cost of 1 brake horsepower-hour on the train will therefore be 1·1 × ·5 = ·55d.

64. Comparison of Water-Power and Coal.—The figures just given show that there is little prospect of economy in the cost of fuel in a country where fuel is cheap. Under other conditions, however, a different result might be obtained. For example, suppose that by means of water-power, or otherwise, electricity could be supplied at ·35d. per unit, and that coal costs from 25s. to 35s. per ton, as is the case in some countries which have plenty of water-power but little or no coal; then the fuel and water would cost more than the electrical energy, and there would be a well-marked economy in favour of electricity. Again, more economical means of generating electric power on a large scale by means of steam plant, and especially by gas producers, are being introduced. This is all in favour of electric railways, for these more economical methods can only be applied to the full extent for the generation of electric power on a large scale in a power house.

65. Expenses.—In addition to the fuel cost, there are, of course, many other expenses in railway working, and in these the electrical method shows marked advantages; for example, wages, oil, stores, repairs, and renewals. There can be no doubt that the item for wages can be largely reduced, and even halved, by electrification. A steam locomotive requires two men, whereas one driver is sufficient for an electric train, and he is driving all the time. On the other hand, a steam locomotive has to have the steam raised and fires banked. The oil and stores account is less; motors usually have self-contained self-oiling bearings, so that the driver does not need to go about with a large oil can before he starts on a trip. The cleaning, when in the shed, is also very much less. The repairs and renewals of steam locomotives are heavy items, due to the presence of the boiler and

the reciprocating mechanism, whereas the electrical equipment of an electric locomotive or a motor coach is comparatively simple and costs less to keep in repair.

66. Summary.—As the comparison of locomotive expenses with steam and electrical operation is not a simple matter, electrification is still regarded as an open question in many quarters. No attempt can be made here to summarize the financial advantages to be expected from electrification, as these vary greatly according to the conditions of each individual case. But as more data become available, it is probable that there will be no difficulty in demonstrating that electric traction has advantages and possibilities which are not possessed by the older form of locomotion. There are indications at the present time that main-line railways will have to spend large sums of money for strengthening bridges, lengthening platforms, etc., in order to cope with the increasing steam traffic. With electric traction this will not be necessary, as shorter, lighter trains running more quickly and more frequently will satisfactorily meet the increased traffic conditions.

DIRECT-CURRENT RAILWAYS

(PART 2)

ROLLING-STOCK ACCESSORIES

RAILWAY MOTORS

CONSTRUCTION AND RATING OF RAILWAY MOTORS

1. Comparison of Railway and Tramway Motors.—Direct-current railway motors are similar in type and general construction to tramway motors, and the early types were practically identical. As railways developed, however, the horsepower required for motor coaches and locomotives increased, in some cases to several thousand horsepower, and thus necessitated differences in size and construction of the motors. The increase in output of the motors is not accompanied by any large increase in space available, because the standard railway gauge of 4 feet $8\frac{1}{2}$ inches is the same as that of most tramways, and the diameter of the driving wheels of electric locomotives and motor coaches is in many cases not much larger than the standard 33-inch diameter wheel of tramcars.

In order to utilize all available space for a railway motor, the bearing at the pinion end projects underneath the armature end connections, and, in some cases, partly under the core itself; the bearing at the commutator end also projects under the commutator hub.

2. Rating of Railway Motors.—As the load on railway motors is intermittent, the horsepower of such motors is given on the

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basis of a run of 1 hour. That is, after the motor has been running at full rated load for 1 hour on a circuit giving the pressure for which the motor is designed, the rise in temperature of any part of the motor as measured by a thermometer must not exceed 135° F., or 75° C. The temperature of the surrounding atmosphere during the test should not be above 77° F., or 25° C. In case it is, proper correction should be made, so that a maximum temperature of 212° F., or 100° C., for any part of the motor shall not be exceeded. If the temperature of a motor exceeds the given value at the end of a run of 1 hour on a certain load, the load should be reduced to comply with the temperature rise and the motor given a lower horsepower rating.

GEARLESS MOTORS

3. Features of Gearless Motors.—A type of motor used on railways, but not on tramways, is the **gearless motor,** in which the armature is mounted concentrically with the driving axle, thus making it possible to dispense with bearings and pinion, so that the space usually taken up by them becomes available for the active electrical parts of the motor. Such a motor must necessarily run at the comparatively slow speed of the axle, and therefore the motor is much larger for a given output than would be the case if it were designed to run at high speed and were geared to the axle. The advantage of extra space available, owing to absence of bearings and gearing, is therefore to some extent counterbalanced by the increased size of the motor. It is necessary to provide the largest railway motors with forced ventilation in order that they may carry the required load without overheating.

4. Arrangement of Armature.—There are two methods of supporting the armatures of gearless motors. The first method is to fix the armature spider directly on the driving axle. It is a somewhat objectionable arrangement owing to the fact that it is usually impossible to support the magnet field system on springs, because the movement of the springs would cause the distance between the poles and the armature to change. If

the field systems are not spring-borne, the total dead weight on the axles and driving wheels is very great, and this weight will cause heavy blows on the track rails wherever there are inequalities, as at the joints, points, and crossings; such blows would be destructive both to the track and the motors.

The second method of supporting the armature is to fix it on a sleeve which loosely surrounds the driving axle, and which is connected to the axle or driving wheels by spring couplings.

5. Early Type of Axle-Mounted Motors.—One of the first railways to have gearless motors was the City & South London Railway, and Fig. 1 represents an early type of Siemens electric

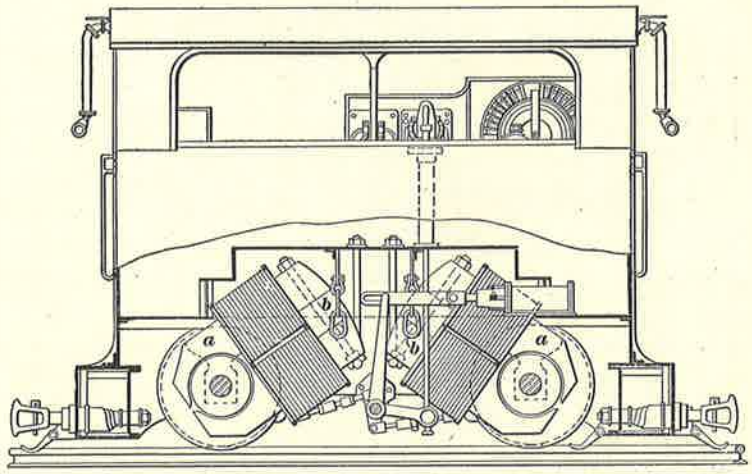


FIG. 1

locomotive used on that line. There are two driving axles, on each of which a motor armature is directly mounted. The motor frame is supported partly by gunmetal brackets *a* on the axles, and partly by means of links from the frame of the locomotive at *b*. By these means the weight of the field magnets and motor frame is partially supported by springs.

The Central London Railway when it was first started used locomotives fitted with 200-horsepower gearless motors, but owing to the vibration which they caused they were replaced by geared motors, and eventually the locomotives were done

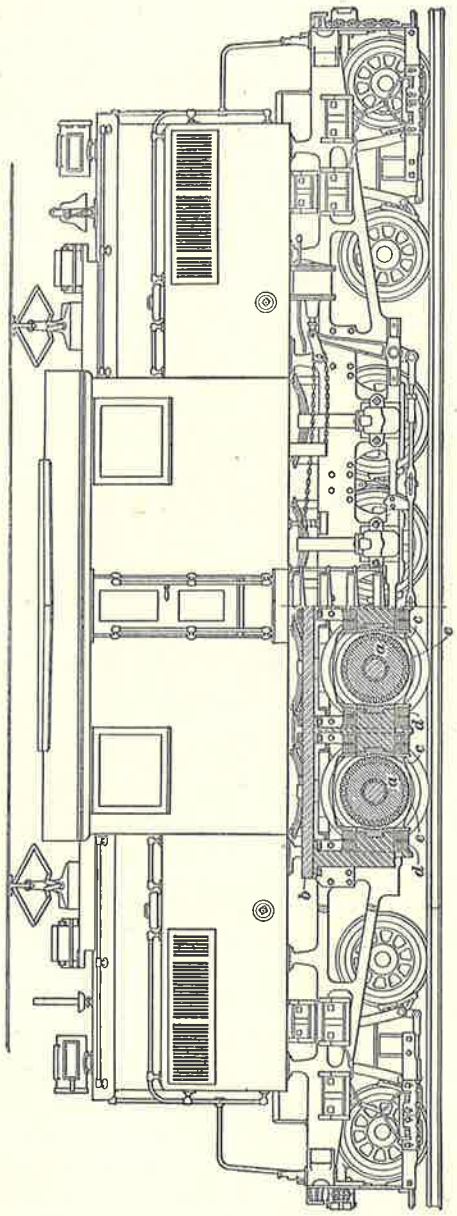


Fig. 2

away with altogether and motor coaches fitted with geared motors were adopted.

6. Locomotive With Bipolar Motors. A view of an electric locomotive fitted with bipolar motors is shown in Fig. 2. Two of the motors are shown in section while the remaining parts of the illustration show the general appearance of one side of the locomotive. The motor armatures *a* are mounted directly on the driving axles, while the field frames *b* form a part of the locomotive underframe and carry the pole pieces *c* and field coils *d*. The pole shoes are only slightly curved and the air gap is large, so the armature can move vertically between the pole pieces without touching. This provision is necessary because the motor frames are spring-mounted, while the

armatures must follow every movement of the axle. A brass screen *e* is fixed between the field poles below the armature to protect it from cinders and pebbles which might be picked up from the roadbed.

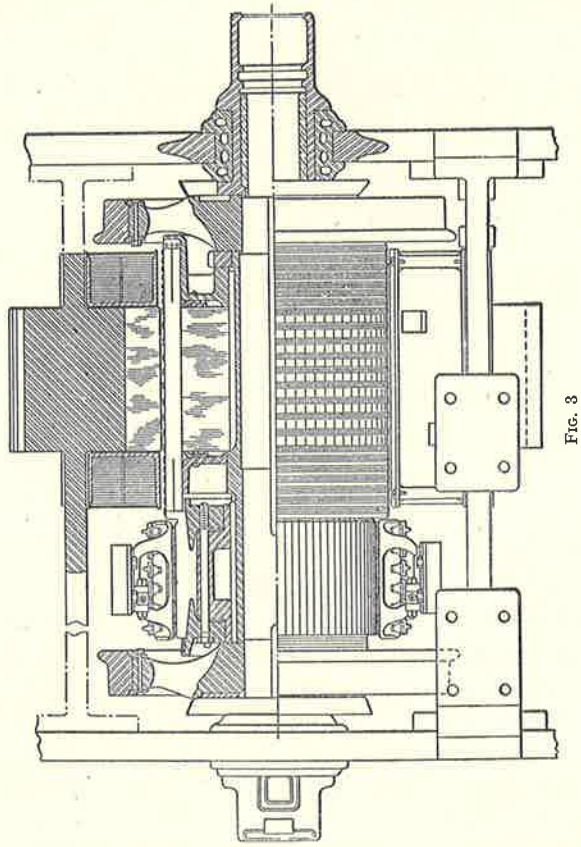


Fig. 3

7. A top view, partly in section, of one of the motors of the bipolar locomotive previously described is shown in Fig. 3. The armature stampings are mounted on a cast-steel spider, and the commutator is built up on a separate spider that is keyed to the armature. After the armature is completed it is pressed tightly on the driving axle after one wheel has been put in place. The brush holders are supported on a frame carried by

the journal-box, and thus always have a fixed position relative to the commutator. This construction is necessary in order to prevent sparking and flashing at the brushes.

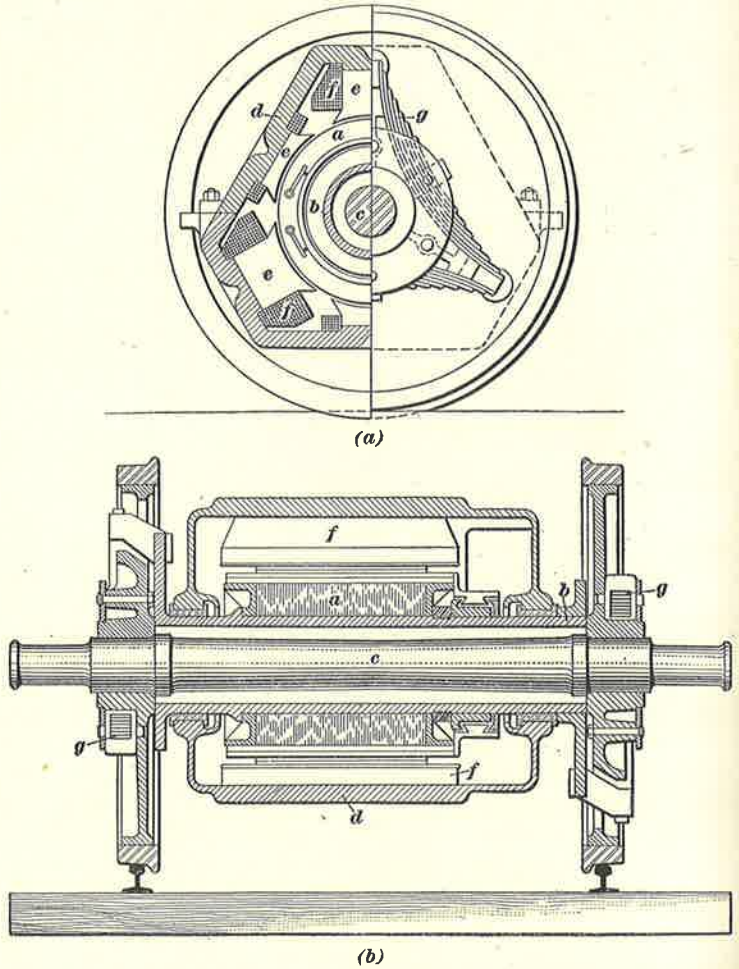


FIG. 4

8. **Example of Sleeve-Mounted Motor.**—Cross and longitudinal sectional views of a sleeve-mounted motor are shown in Fig. 4 (*a*) and (*b*). The armature *a* is mounted on a sleeve *b* having the

main axle *c* inside, a certain amount of play being allowed. The frame of the motor *d* is supported on the sleeve and carries the poles *e* on which are the field coils *f*. The sleeve is connected to the track wheels through the leaf springs *g*, so that the entire motor is borne on springs, thus reducing the shock to both track and motor.

9. **Locomotives Fitted With Coupling Rods.**—It is now usual to fit large electric locomotives with coupling rods, so that the motors can be raised well above the axles where there is plenty of room, thus securing better ventilation and making possible the installation of larger motors than can be used otherwise. The side rod also raises the centre of gravity of the locomotive and permits the motor to be mounted on the spring-borne frame, so that the wear and tear on the track is very much reduced,

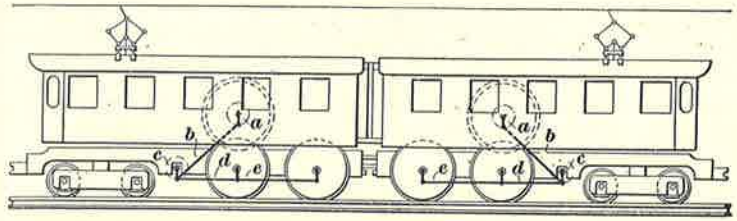


FIG. 5

and, also, the motors can be easily cared for. The raising of the centre of gravity is a decided advantage, especially if a locomotive is to run at high speed round curves. A train tends to move in a straight line, and when rounding a curve it exerts a heavy pressure on the outer rail due to the centrifugal force. If the centre of gravity is low, this force tends to move the rails out of position; but if the centre of gravity is high, there is a tendency to overturn the locomotive, thus making the treads of the wheels and rails take the pressure and relieving the flanges and reducing the side thrust on the rails.

10. A 4,000-horsepower direct-current locomotive which is divided into halves, each fitted with a 2,000-horsepower ten-pole 600-volt motor provided with forced ventilation, is shown in Fig. 5. The motors are supported on the main spring-borne

frame of the locomotive and are connected to the 68-inch diameter track wheels by means of cranks and connecting-rods.

The armature shaft of each motor is provided with cranks *a* at each end, the cranks at opposite ends of the shaft being placed at an angle of 90° to each other. Each crank is connected by means of a connecting-rod *b* to a shaft *c* which is carried by the locomotive frame, so that the distance between its centre and the centre of the motor shaft is fixed. Connection to the cranks on the driving wheels is made by coupling rods *d* and *e*. It is possible to completely counterbalance the weight of the cranks and connecting-rods, because the motion at each end of each connecting-rod is rotational, and thus do away with any pounding of the track. With a steam locomotive, it is not possible to balance the reciprocating parts by counterweights on the driving wheels. The centre of gravity of this locomotive is about 80 inches above the rails, or practically the same as for a steam locomotive, so that it takes curves easily. The maximum tractive effort of 60,000 pounds is sufficient to start a train weighing 550 tons, and the normal speed is 60 miles per hour.

GEARED MOTORS

11. Gearing.—Chain gearing has been used for some of the smaller locomotives for industrial work, and it has the advantage of enabling the motor to be wholly spring-borne, but it is not suitable for large locomotives or for motor coaches because of the first cost and wear and tear. Double helical gear-wheels give very quiet running when the teeth are machined and are very strong, but they also are very expensive. The standard gearing for railway motors is therefore a pressed fluid-steel pinion meshing with a cast-steel wheel, both having accurately cut teeth. The gear ratio seldom exceeds 5 to 1, and a peripheral speed of 3,000 feet per minute should not ordinarily be exceeded.

12. British Thomson-Houston Geared Motor. — A cross-sectional view of a B.T.H. (British Thomson-Houston) 200-horse-power, geared, heavy-traction type motor is shown in Fig. 6. The bearings *a* and *b*, which project under the end connections

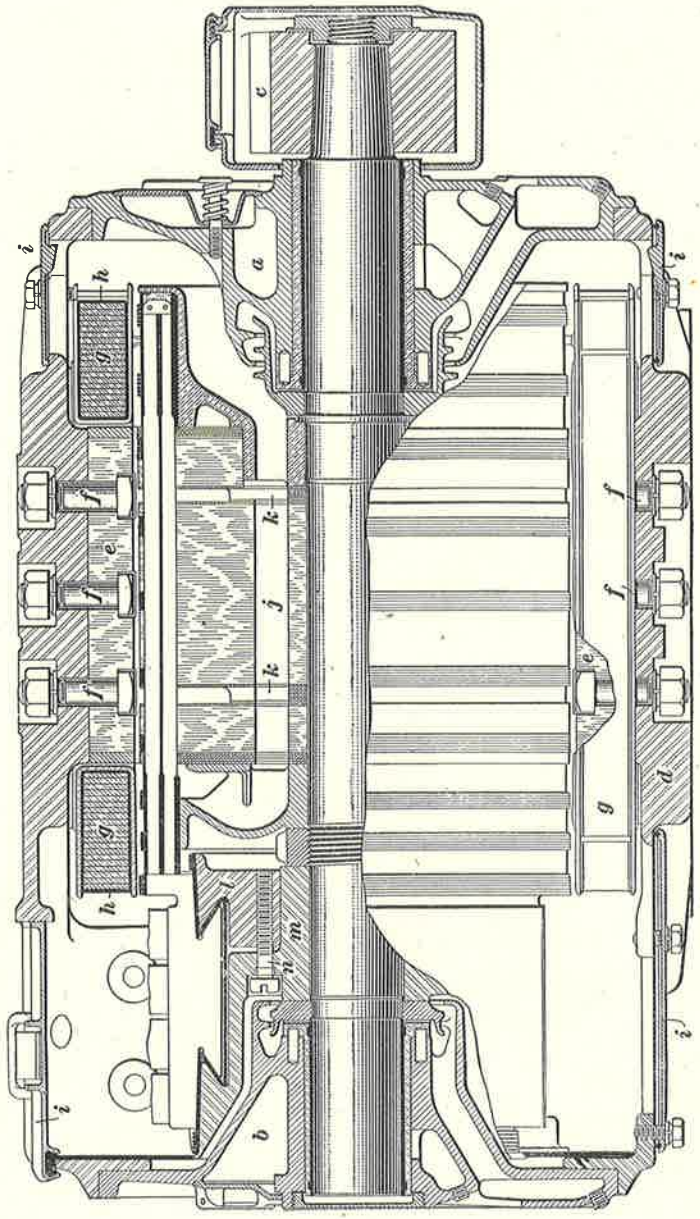


FIG. 6

and commutator hub in order to save space, are carried by the circular end plates, which are securely bolted to the motor casing *d*. The pinion *c* is fastened to the shaft by means of a key and locknut. The shaft is tapered in order to facilitate the removal of the pinion when necessary. There are four laminated poles *e*, two of which are shown, each bolted to the frame by three bolts *f*. Each pole is surrounded by a field coil *g*, which is made up of copper strip insulated with asbestos, so that it can withstand a high temperature without injury. The space occupied by the strip winding is much smaller than would be required if the coil were wound with round wire. It is necessary to insulate thoroughly each coil from the frame, as indicated by the heavy lines *h*. Openings into the casing for purposes of inspection and for adjusting the brushes are provided with covers *i* held in place by bolts. The armature core is provided with ventilating channels, one of which is shown at *j*, near the shaft, and radial ducts *k* pass from the channels to the outside of the core. The commutator boss is made in two parts *l* and *m*, the latter arranged to overhang the bearing *b*; the two parts are held together by bolts *n*.

13. Removal of Armature.—As the casing of the motor is cast in one piece, the armature must be inserted and removed by taking off one of the end plates. In order to facilitate the

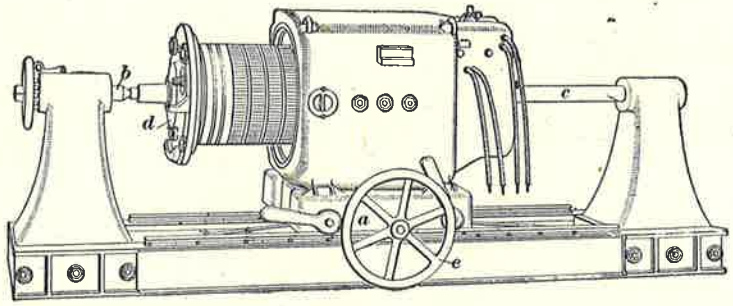


FIG. 7

removal of the armature for repair a special stand, as shown in Fig. 7, is provided. The motor casing is placed on a sliding base *a* and the armature shaft is placed between centres *b* and *c*.

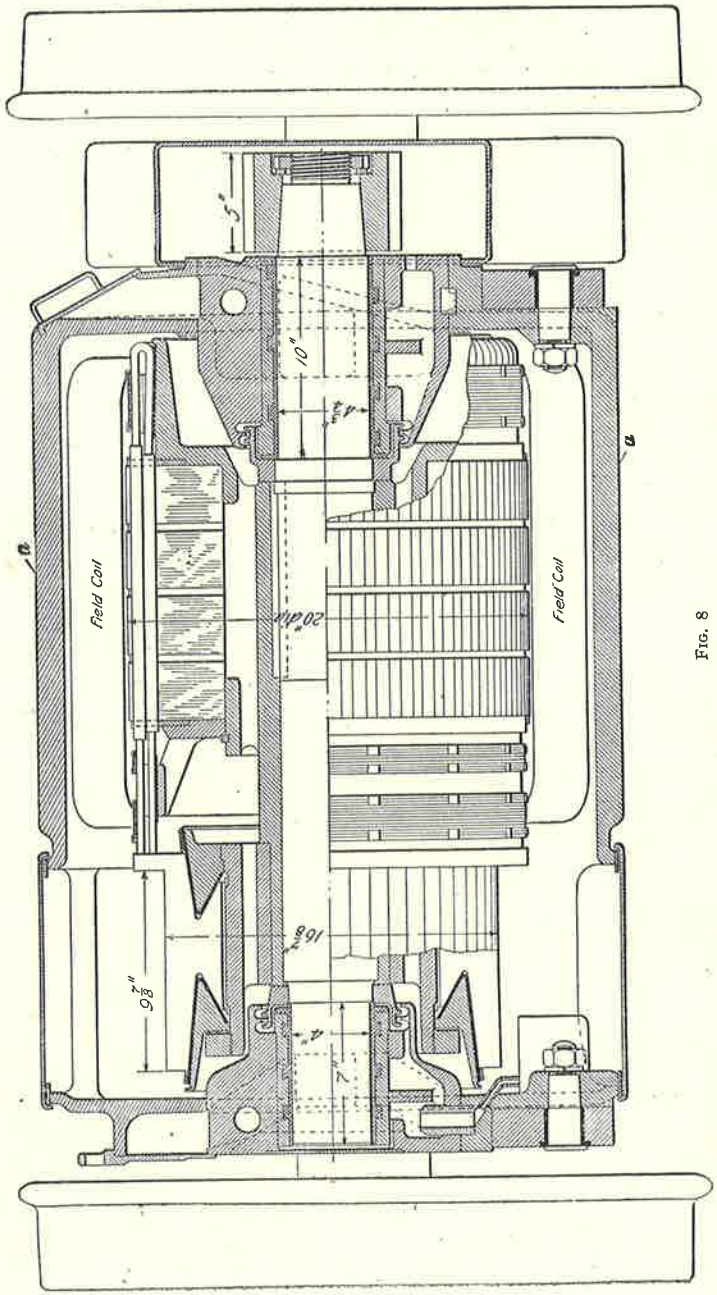


FIG. 8

After the end bearing plate *d* has been unbolted, the motor casing can be moved to the right by turning the hand wheel *e*.

14. Westinghouse Geared Motor. — A sectional view of a Westinghouse railway motor, which can deliver 200 horsepower for 1 hour without overheating, is shown in Fig. 8. The frame, or casing, *a* is made in two parts, and the four poles are arranged diagonally instead of vertically and horizontally, as in the large British Thomson-Houston motors. The armature is provided with ventilating ducts, and the casing with inspection openings fitted with covers.

15. Siemens-Schukert Commutating-Pole Motor.—The greater efficiency of transmission possible when high voltages are used

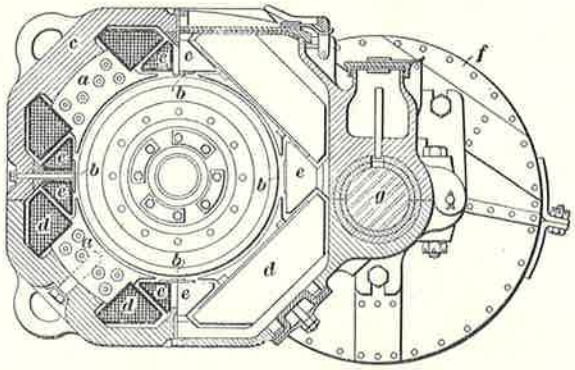


FIG. 9

has led engineers to consider the application of high voltage to direct-current railway motors. This introduces two important difficulties: (*a*) it increases the possibility of a breakdown of insulation, and (*b*) it increases the liability of flashing over between the brushes on the commutator. The first of these difficulties is overcome by providing extra-quality insulation of sufficient thickness, and the second is in some cases minimized by the employment of commutating poles.

Fig. 9 shows a section through a 1,000-volt Siemens geared motor of 130 horsepower. The four main poles *a* are laminated, but the commutating poles *b* are solid, slots being made in the ends to reduce eddy currents. All the pole pieces are bolted

to the frame *c* of the motor, which is cast in halves. The windings *d* and *e* of the main and commutating poles, respectively, are suitably shaped in order to make the best use of the space available; the windings of the commutating poles are permanently in series with the armature. The gear-case is shown at *f* and the locomotive driving axle at *g*.

ARMATURE BEARINGS

16. Plain Bearings.—The bearings of railway motors must be arranged to be as nearly dust-proof as possible, and the system of lubrication must be simple and effective. For the sake of simplicity, plain bearings, such as are shown in Figs. 6 and 8, are used on many railway motors. Oil, and not grease, is almost invariably employed as lubrication. A common form is the wick type, in which oil is fed by the capillary action of the wick on to the top of the journal and along which it is carried by grooves in the bearing bush. Pad lubrication is also largely used; two pads of wool or cotton-waste in the oil chamber press against the journal at points somewhat below the horizontal diameter; the oil is thus evenly distributed without the aid of grooves.

17. Ring-Oiling Bearing.—The lubrication of the Dick-Kerr railway motors is effected by means of oil rings similar to those used for dynamo bearings. The armature bearing boxes are solid castings entirely independent of the main motor frame. The rings dip into the oil contained in a chamber below the axle, and large drain channels are provided to carry away any oil which may be thrown out of the chamber or bearing. Oil throwers prevent oil from creeping along the shaft to the windings. After the bearings have been filled with oil they will run for a fortnight without attention, although it is good practice to have a regular system of oiling once a week.

MOTOR SUSPENSIONS

18. Necessity for Spring Suspensions.—The four-wheeled trucks fastened under each end of a locomotive or motor coach by means of a swivel bolster, and usually called **bogies**, require to be

much stronger in electric rolling stock than for steam working. This is because they have to carry the motors and other electric equipment, and considerable stresses are set up by the direct weight and the torque produced by turning action of the motors. In order that the torque of the motors may be transmitted to the driving wheels, it is essential that the frames of the motors be properly supported on the truck and prevented from turning. One side of a geared motor is always supported by the axle, and the other side is spring-borne. The two most widely used methods of suspending railway motors are, respectively, the *nose suspension* and the *cradle suspension*, and these suspensions are modifications of the styles used on tramcars.

19. Nose Suspension.—In many instances, the motor casing is provided with a projecting lug, or nose, at the side opposite

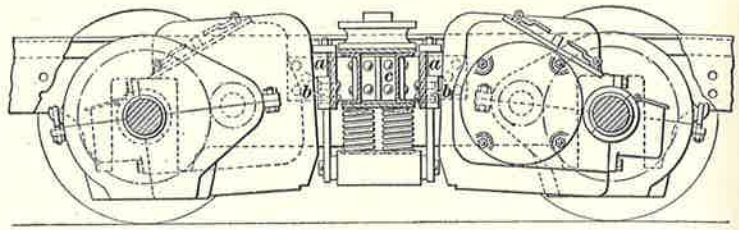


FIG. 10

to that carried by the axles. The projection, or nose, is supported in a suitable manner, and this type of suspension of the motor is called the **nose suspension.** A view of a bogie carrying two motors provided with nose suspension is shown in Fig. 10. Each motor has a nose *a* which fits into a bracket *b* on a bar which is supported from the spring-borne bolster *c*. A part of the weight of the motor is thus carried on springs.

20. Cradle Suspension.—When a motor casing is supported by bars or a frame passing underneath, or attached to lugs at the sides, the motor is said to have a **cradle suspension.** In the Baldwin-Westinghouse cradle suspension shown in Fig. 11, the motors are hinged to the axles *a* by bearings in the ordinary way. Between the axle bearings on each motor case is a projection *b* supporting a spring *c* from which hangs a bolt connected

to a transverse beam *d*. The two beams *d*, *d* form the end members of a rectangular cradle having side members *e*. On each motor there are two forked projections *f*, one situated under each armature bearing. These projections rest on and are bolted to the longitudinal members *e* of the cradle. The motors are supported directly under the armatures ; this reduces the stress on the motor casing and the pressure on the bearings. The weight of the motors draws down the cradle and compresses the springs *c*, *c*. The light spring *g* under the projection *b* on the motor frame is to damp out any tendency of the motor to vibrate up and down due to inequalities in the track.

21. Axles.—As the driving axles of electric locomotives and motor-driven coaches directly support part of the weight of the

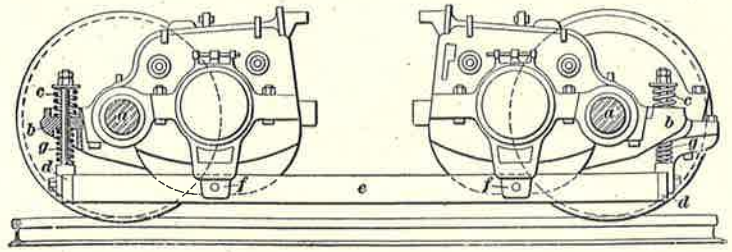


FIG. 11

motors, and are, in addition, subjected to a twisting moment, it is necessary that they be made of larger diameter than the axles of trailers.

The motor coaches of the Central London Railway have driving axles $5\frac{1}{4}$ inches in diameter, and the axles of the trailers have a diameter of $4\frac{3}{8}$ inches, the measurements in both cases being taken at the centres of the axles. The motor coaches on most of the other electric railways in London have driving axles 6 or $6\frac{1}{4}$ inches in diameter, while the axles of the North Eastern Railway locomotives are 7 inches in diameter at the centres.

MOTOR COACHES

22. Central London Railway Coach.—Not only are the bogies for electric railways heavier than those in use on steam railways, but the underframes of the motor coaches are also heavier.

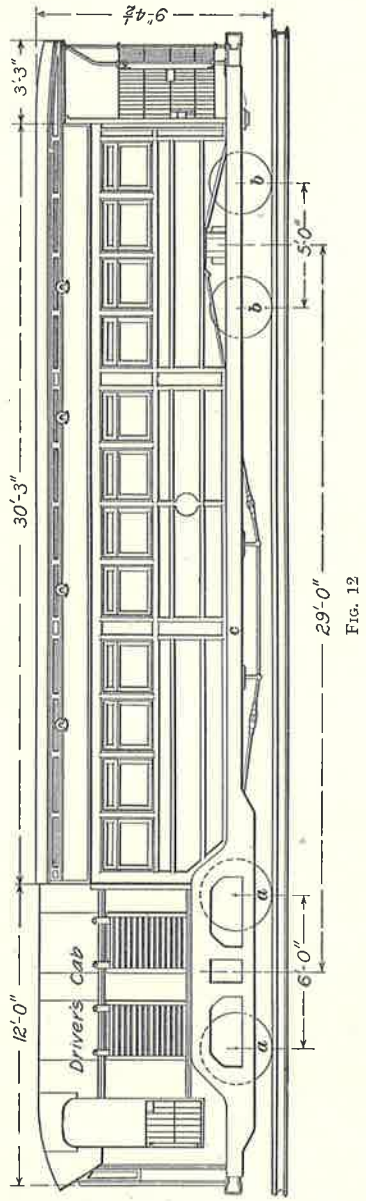
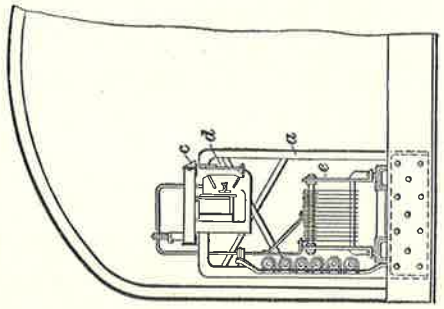


Fig. 12

This is necessitated by the additional weight which they have to carry, due to the cables, contactors, reversers, resistances, and to the modifications to prevent fire in case of a short circuit. With the exception of these, motor coaches for surface electric railways do not differ widely from those in use on steam railways; but for tube railways, as space is very limited, there are many differences in design. For example, the trailer coaches of tube railways have the end sections fitted with longitudinal seats, and under the seats the structure is cut away to leave room for the tops of the track wheels. This is not possible in motor coaches, because of the space occupied by the motors, and therefore the floor level is raised in the driver's compartment at the end of the coach. This construction is shown in Fig. 12, which is an outline of a motor coach used on the Central London Railway. The driving, or motor, end is shown at the left, the driving wheels being indicated at *a*, *a*. The other end of the car is carried on a trailer bogie, the wheels being marked *b*, *b*. The longitudinal girder *c* of the underframe is straight at the



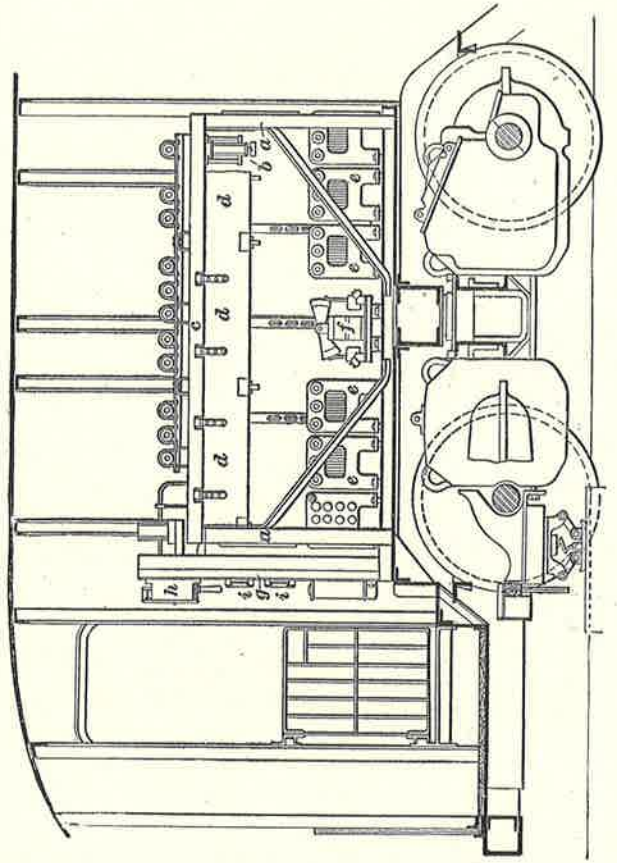


Fig. 13

trailer end, but is curved upwards at the motor end. The longitudinal girders support the cross-members of the underframe, and the floor level in the driver's cab is raised sufficiently to clear the motors.

23. Arrangement of Driver's Cab.—In many cases part of the control apparatus, such as the electromagnetic switches, or contactors, etc., are placed under the body of the coach, but in other cases the whole of the control apparatus is concentrated in the driver's cab. Thus, in the motor coach shown in Fig. 12, the cab contains the master controller, contactors, resistances, and reverser; the main switch and fuses; the switches and fuses for the compressor and lighting circuits; the compressor, air reservoirs, sand box, and tool chest; the air brake, operating valve, whistle, sand cocks, hand-brake, ammeter, voltmeter, and air gauge.

Fig. 13 (*a*) and (*b*) shows the arrangement of the apparatus on the contactor-frame side of the cab of a Central London Railway motor coach. The frame *a* is made of steel angle bars and supports the contactors *b*, which are bolted directly to the top bar *c* of the frame. The shields *d* in front of the contactors are for the purpose of protecting any person, passing the contactor frame, from the effect of the arcs which are formed when a contactor opens. Below the contactors are the resistances *e* and the reverser *f*. At the forward end of the frame *a* is the switch panel *g* containing the main switch *h*, fuses *i*, and other hand-operated switches. A similar arrangement of apparatus is adopted on the Great Northern, Piccadilly & Brompton and the Baker Street & Waterloo Railways.

24. Risk of Fire.—Great care has to be taken on tube railways to minimize risk of fire, and one great step toward the attainment of this end was the introduction of all-steel coaches, which are now used on such underground railways. Wood is, of course, necessary for interior furnishing, but it is subjected to special treatment to render it non-inflammable, and the amount of wood used is made as small as possible. In the Central London Railway coaches the driver's cab is constructed of steel throughout, except the doors in front of the driving platform, which are

of teak. The space between the passenger compartment and the rear bulkhead of the cab is packed with asbestos, and the end panelling of the passenger compartment is made up of *uralite*, which is a special fireproof sheathing, veneered with sycamore. On the Great Northern, Piccadilly & Brompton Railway the coaches are lined with asbestos millboard covered with a veneer of mahogany less than $\frac{1}{16}$ inch thick.

CURRENT COLLECTORS

COLLECTORS FOR CONDUCTOR RAILS

25. General Types of Collectors.—On many electric railways the negative, or return, conductor of the circuit is formed by the track rails, and an insulated third rail is the positive, or feeding,

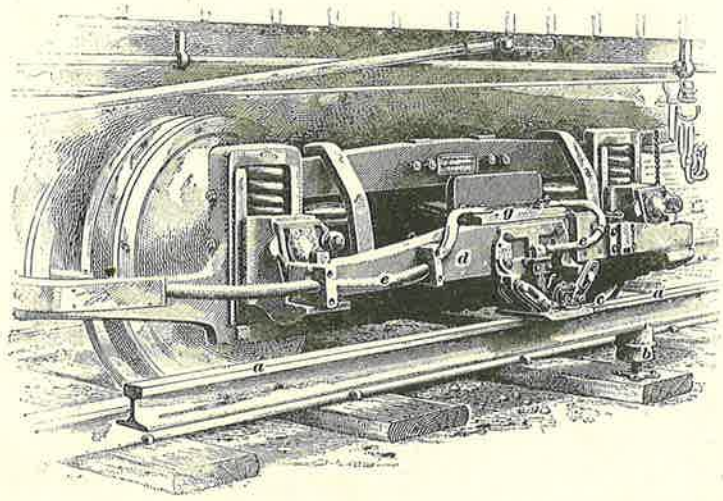


FIG. 14

conductor. On other railways, a fourth conductor rail, either alone or assisted by the track rails, forms the return circuit. For each of these rails sliding contacts, or *collector shoes*, are necessary. On the other hand, some railways, especially those

of the industrial type, take current from overhead trolley wires, the collector in this case being either a trolley wheel or a sliding bow. Some of the small electric locomotives for factory and mining work have a grooved gunmetal shoe pressing against the under side of the trolley wire.

26. Arrangement of Collector Shoes.—A general view of a positive conductor rail *a* supported on insulators, one of which is shown at *b*, and having a collector shoe *c* resting on it, is shown in Fig. 14. The shoe frame is suspended from a wooden beam *d*, which is attached to the axle blocks. A terminal piece on the shoe frame has a cable *e* connected to it and a flexible copper

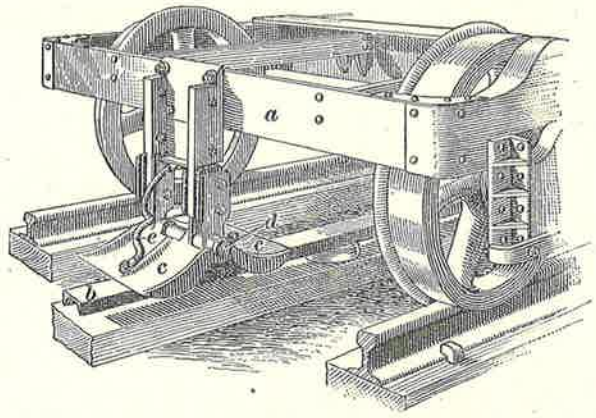


FIG. 15

connection *f* between it and the shoe *c*, so that current is carried direct instead of through the suspension links. The fuse *g* is for the purpose of cutting off current in case of a short circuit. Some of these collectors carry very large currents; for example, on the Liverpool & Southport line, a train weighing 144 tons requires about 2,400 amperes during acceleration. Also, the locomotives of the Pennsylvania Railway are fitted with two 2,000-horsepower motors, each of which requires 2,900 amperes when running at full load.

27. Collector on Liverpool Overhead Railway.—Although it has been superseded by other types, the collector shown in

Fig. 15 is very effective and simple. The shoe is suspended from a transverse beam *a* of the motor truck, and, of course, in this position it is only suitable for a conductor rail *b* laid between the track rails. The collector shoe consists of two parts *c*, *c* hinged at *d* and provided with flexible conductors *e* to carry the current to the shoe support. This type of collector has been used on the Liverpool Overhead Railway.

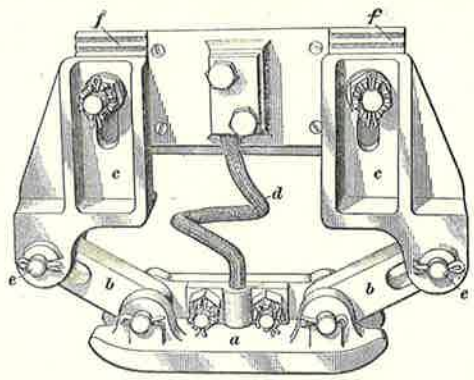


FIG. 16

28. Link-Suspended Collector.—The collector shown in Fig. 16 is known as the **link-suspended type**, and it is the one most used in Great Britain. The shoe *a* is of cast iron, and it is suspended by steel links *b* supported from a cast-steel framework *c*; the flexible cable *d* takes current direct from the shoe to the framework, so that it does not have to pass through the hinge pins *e*. The corrugated surfaces *f* are for the purpose of adjusting the height of the shoe to allow for varying diameters of the track wheels as

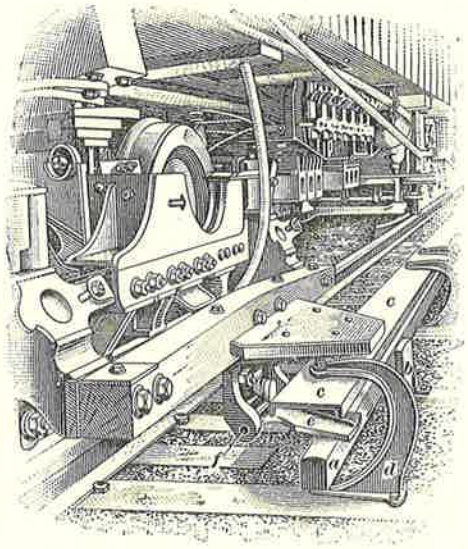


FIG. 17

they wear down and at the same time to give general rigidness to the collector-shoe frame. There is no spring to force the shoe down, as its own weight is sufficient to ensure good contact.

29. Ice on Conductor Rail.—The guards over the third rail are to prevent workmen from coming in contact with the live conductor, and also to protect the third rail from snow and ice. When the temperature drops below freezing while rain is falling, there is a liability of a thin skin of ice or sleet being formed on the third rail. This does not often happen in Great Britain, but it has given considerable trouble in the United States, because the ice will not conduct current and is difficult to remove.

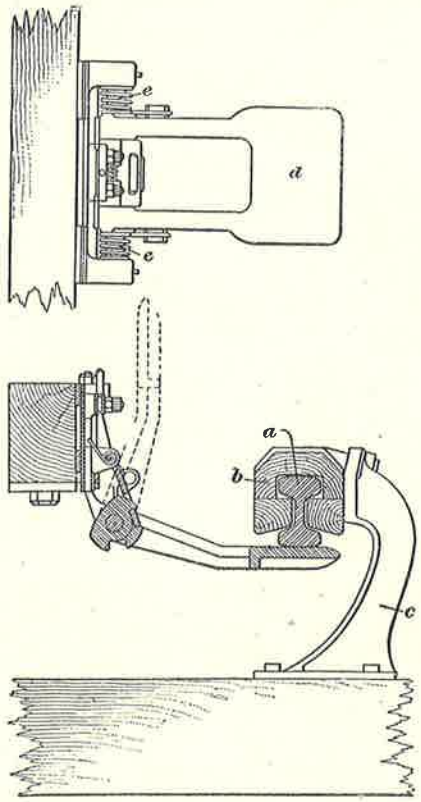


FIG. 18

There are a number of methods for preventing the formation or adherence of ice on the conductor rail; for instance, swabbing the surface of the rail with oil, sprinkling brine or a solution of calcium chloride on to the rail from a tank carried on a special car, and covering the rail with an overhanging guard, as shown in Figs. 17 and 18. On many railways, however, the only protection of the conductor rail is by planking laid along each side, and in such cases sleet can form freely on the surface if the climatic conditions are favourable.

30. Collectors for Protected Conductor Rail.—In some installations the conductor rail is protected, and this makes a special form of collector necessary, as shown in Fig. 17. The conductor rail *a* is of rectangular cross-section, so as to be easily manufactured, and is supported on insulators *b*. The protective cover *c* of the conductor rail is made of channel iron and is carried on cast-iron brackets *d*. The collector shoe *e*, hinged at *f*, projects over and rests on the conductor rail. The shoe is light in weight, so a spring is provided to give the necessary pressure between the shoe and the rail.

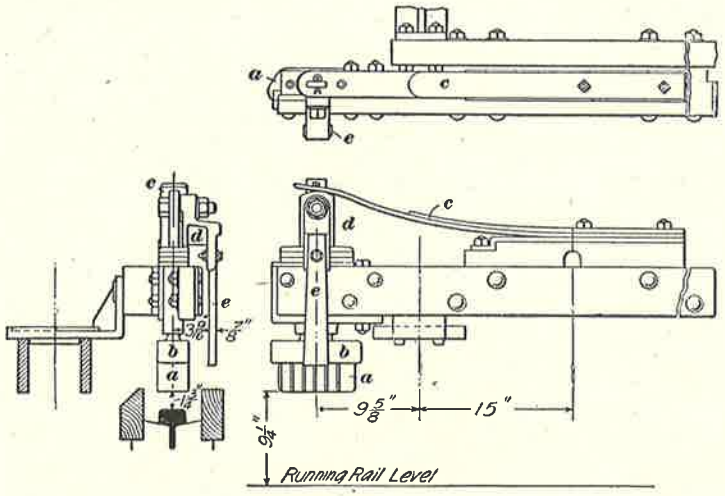


FIG. 19

31. Under-Running Collectors.—Side and top views of a special form of collector shoe are shown in Fig. 18. The conductor rail *a* is suspended from insulators *b*, which are clamped to cast-iron supports *c*. In order to secure unbroken contact the collector shoe *d* must be pressed up against the bottom of the rail. The necessary pressure is secured by the coiled springs *e*, which are shown in the plan view.

32. Sleet Brush.—Sleet brushes are frequently used to remove the ice from the rail, and Fig. 19 shows top, end, and side views of the type of brush or scraper used on the New York Elevated Railway. It consists of a number of thin hard-steel plates *a*

cast into a block *b* and having their edges bearing hard against the surface of the rail, the laminated spring *c* giving the necessary pressure. In order that the steel plates shall not catch on the rail joints they are set diagonally across the rail. A cam *d*

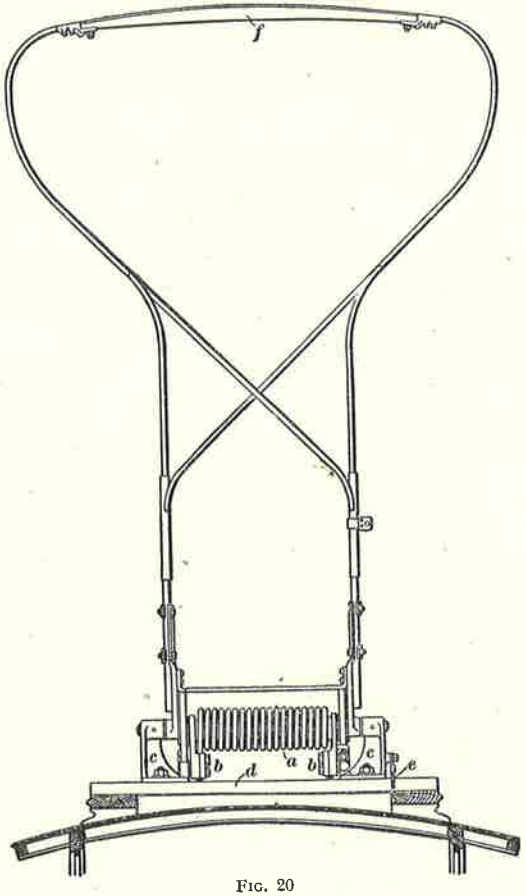


FIG. 20

controlled by the arm *e* is provided to hold the brush off the rail when it is not required. One of these brushes is placed near each contact shoe on each car, and where the trains run at short intervals the formation of ice can generally be kept in check.

COLLECTORS FOR OVERHEAD CONDUCTORS

33. Bow Collector.—The **sliding,** or **bow, collector,** which has been much used on tramways, was first introduced on the Continent by Siemens and Halske. Even at the comparatively low speeds of tramcars, the bow collector shows some advantages over the trolley wheel, but for high speeds and heavy trains the bow is in every way considered as superior to a wheel, as it cannot run off the trolley wire, has no tendency to *chatter*, and requires but little attention. A modern type of bow collector suitable for a railway is shown in Fig. 20. The bow slants back from the vertical position when pressed against the under side of the trolley wire, and the steel spring *a* is wound tighter or unwound according to the direction in which the bow is bent over. The ends of the spring are fixed to brackets *b*, one or the

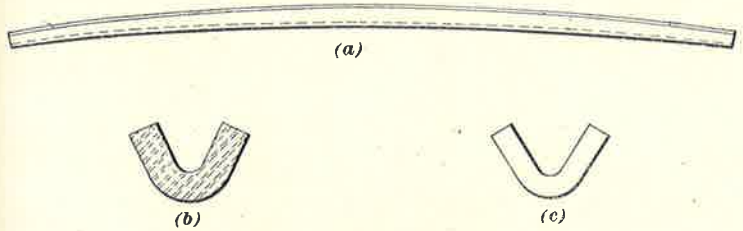


FIG. 21

other of which bears against a projection on one of the fixed brackets *c* when the bow is moved either way from a vertical position. The fixed brackets *c* are supported on a plate *d*, carried on the top of the motor coach, and insulated from it. Current is led away to the motors by the cable *e*.

34. Sliding Strips.—The sliding, or contact, strip *f* at the top of the bow collector, Fig. 20, is made of aluminium, as the lightness of this metal enables the weight and inertia of the collector to be so reduced that a comparatively small upward pressure is sufficient to cause the bow to follow inequalities in the height of the wire. The contact strip shown at (*a*) in Fig. 21 contains a deep groove filled with grease for lubricating the trolley wire and thus making the motion of the bow noiseless and reducing

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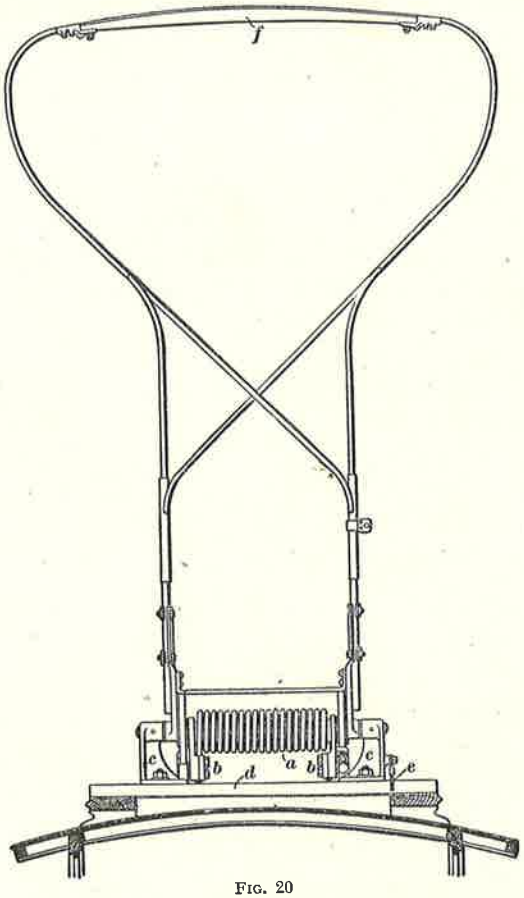

FIG. 20

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COLLECTORS FOR OVERHEAD CONDUCTORS

33. Bow Collector.—The **sliding, or bow, collector,** which has been much used on tramways, was first introduced on the Continent by Siemens and Halske. Even at the comparatively low speeds of tramcars, the bow collector shows some advantages over the trolley wheel, but for high speeds and heavy trains the bow is in every way considered as superior to a wheel, as it cannot run off the trolley wire, has no tendency to *chatter*, and requires but little attention. A modern type of bow collector suitable for a railway is shown in Fig. 20. The bow slants back from the vertical position when pressed against the under side of the trolley wire, and the steel spring *a* is wound tighter or unwound according to the direction in which the bow is bent over. The ends of the spring are fixed to brackets *b*, one or the

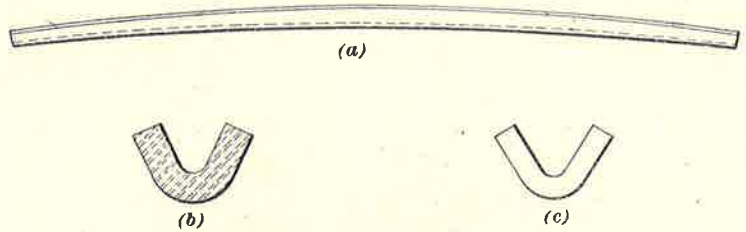


FIG. 21

other of which bears against a projection on one of the fixed brackets *c* when the bow is moved either way from a vertical position. The fixed brackets *c* are supported on a plate *d*, carried on the top of the motor coach, and insulated from it. Current is led away to the motors by the cable *e*.

34. Sliding Strips.—The sliding, or contact, strip *f* at the top of the bow collector, Fig. 20, is made of aluminium, as the lightness of this metal enables the weight and inertia of the collector to be so reduced that a comparatively small upward pressure is sufficient to cause the bow to follow inequalities in the height of the wire. The contact strip shown at (*a*) in Fig. 21 contains a deep groove filled with grease for lubricating the trolley wire and thus making the motion of the bow noiseless and reducing

wear on the wire. The metal is thicker in the middle than at the ends, as shown by section (*b*) and end view (*c*), to allow for the greater wear near the centre of the bow. Under ordinary circumstances, the life of a contact strip is found to be 30,000 car miles, although higher figures have been obtained.

35. Reversible Bow Collector.—The bow collector described in the previous article is reversed at the end of each journey by suspending the trolley wire at such a height that the bow stands nearly upright. Then, when the motor coach starts off

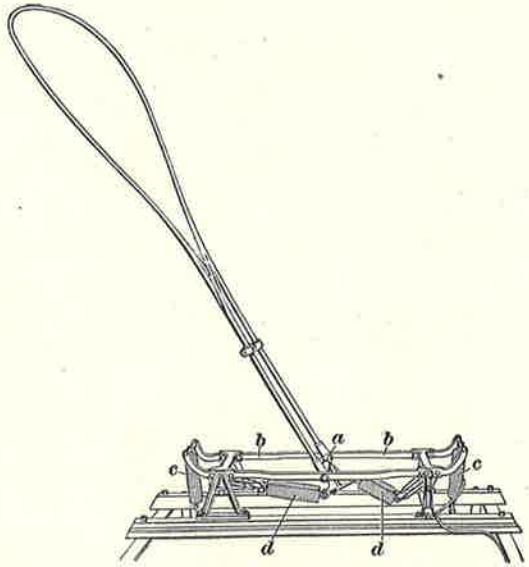


FIG. 22

in the opposite direction, the bow automatically lays over at the required angle because of the friction between the trolley wire and contact strip. Of course, in locomotives used for shunting, it is necessary that the bow should reverse itself at any point on the line, instead of only at the reversing points where the height of the trolley wire has been specially increased. The Siemens-Schukert bow, shown in Fig. 22, has been specially designed to suit the condition. The horizontal axle *a* on which the bow rotates is carried on double levers *b* held in position by

springs *c*. When the vertical pressure on the axle increases, as it does when the direction of motion is reversed, the axle moves downwards and the bow reverses itself automatically. The bow is pressed against the trolley wire by two pairs of springs *d*, which are attached to any extension of the bow frame below the axle *a*.

36. Bow Collector for Large Currents.—For very large currents the type of collector shown in Fig. 23 or Fig. 24 is used. In the collector shown in Fig. 23 the short bow *a* is pivoted at *b*, and the framework *c*, pivoted at *d*, is capable of being raised and

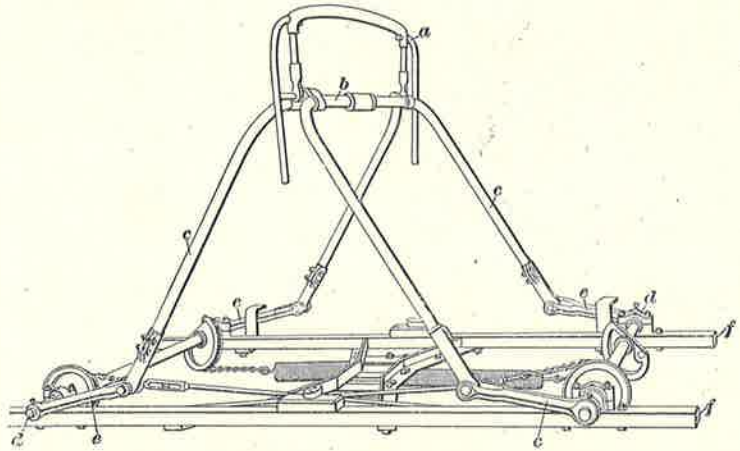


FIG. 23

lowered by the driver, so as to bring the bow into or out of contact with the trolley wire. As shown in the illustration, the collector is in the raised position; when lowered, the cranks *e* are below the horizontal bars *f*. This lowering is required not only to reverse the bow, or break contact with the trolley wire, but it also has to be done when passing under bridges where the trolley wire is lower than in the open.

37. Air-Operated Collector.—Electric locomotives which require large currents are in some cases fitted with the type of collector shown in Fig. 24. This collector is of very heavy

construction, and is intended specially for overhead conductor rails in tunnels or storage yards. The bow collector *a* is supported by the arms *b*, *c*, *d*, *e*, the lower arms *d* and *e* being connected by the strips *f*, *g* to the crosshead of a piston rod working in the air cylinder *h*. The air cylinder is provided with supply pipes so that compressed air may be admitted above the piston, thus driving the crosshead down and raising the bow *a*. In order to lower the collector, it is only necessary to release the air above the piston and the arms will collapse until the bow rests on the top of the cylinder.

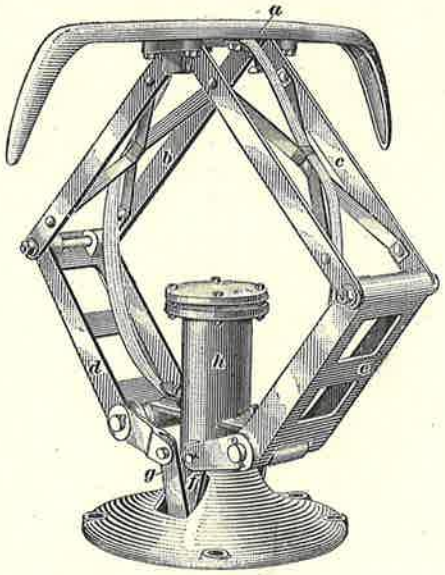


FIG. 24

SYSTEMS OF CONTROL

GENERAL REQUIREMENTS OF CONTROL SYSTEMS

WIRING CONSTRUCTION

38. Board of Trade Regulations.—The Board of Trade have made a number of rules regarding the precautions which must be taken in the construction and operation of motor-driven coaches and trains. The rules which apply specially to underground railways are as follows:

1. Cars to be constructed of metal; woodwork to be reduced to a minimum and to be non-inflammable. Hard wood must be used in preference to soft. Interior fittings, panels, seats, etc., to be of incombustible material.

2. No main electric cable to be carried through the train, and motors to be placed on the front and rear carriages only. No motor to be situated in the middle of the train.

3. Means to be provided at both ends of every train to enable passengers to alight from the cars in case of emergency. Oil lamps to be carried in every train.

4. India-rubber or other inflammable insulating materials to be avoided as much as possible, and the outer covering of cables to be uninflammable material that will not give off smoke.

5. Means to be provided for enabling a driver at any part of the tunnel to put himself into telephonic communication with the adjacent stations.

39. General Arrangement of Wiring.—The electric wiring for motor coaches includes not only the control wires, but also the main power circuits. As the control wires must run from end to end of the train, **coupling cables,** or **jumpers,** which are short lengths of cable having the number of wires necessary for the control circuits and arranged with suitable connectors, must be provided between the various coaches to connect the control systems. If a train is made up of several motor coaches, the feed-wires from the collector shoes are sometimes connected to heavy conductors called **bus-lines,** which run the entire length of the train. The object of the bus-line is to supply all the motors with current, though some of the collector shoes may not be in contact with the supply conductor. For underground railways the Board of Trade will not allow bus-lines, so their use is limited to surface railways. To guard against fire, the contactors are enclosed in fireproof compartments, all the main wiring is run in iron pipes, or conduits, and the outer insulation of the flexible cables must be non-inflammable. In some instances the wiring is contained partly in wooden troughing cased with uralite, as this material is an insulator as well as being non-inflammable.

40. Conduits.—Where wood is used in the body of the car, the conduits may be cleated to the under surface of the body. On underground lines, where all-steel cars are used, the conduits are passed through holes in the transverse beams or are carried by brackets fixed to the under side of the transverse beams or longitudinal girders. Sometimes the conduit is coated with

enamel inside or inside and out. This treatment enables the cables to be easily drawn in, provides additional insulation, and prevents rust. Wherever possible, the conduits are given a slope so that any water that may condense inside drains to a point where it can be drawn off. In order to prevent abrasion of the insulation where the cable leaves the conduit, a collar of rubber or other yielding material is provided.

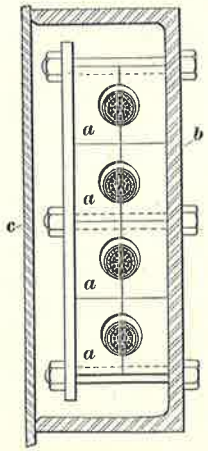


FIG. 25

41. Porcelain Cleats.—On the Great Northern & City Railway the train cables are supported in **porcelain cleats,** as shown in Fig. 25. The cleats *a* go inside the longitudinal members of the underframe *b* of the coach, and the channel is closed by a steel plate *c*.

42. Control Couplers.—All the train wires on a coach are united into a train cable, which is provided at each end of the car with a socket in which there is a plug or pin connected to each train

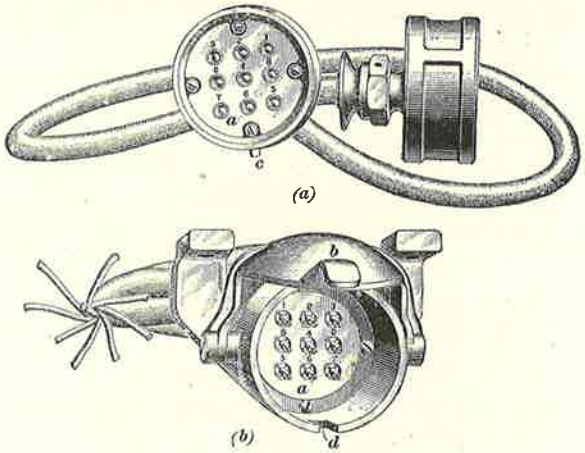


FIG. 26

wire. At each end of each **jumper,** or **control coupler,** is a plug that fits into the socket on the end of the car cable. In the

plug there is a receptacle at the end of each of the jumper wires, and these receptacles fit over the corresponding plugs in the car-cable socket. A jumper for several wires is shown in Fig. 26 (*a*), and the corresponding socket on the train cable is shown in view (*b*). The receptacles in the jumper plug are shown at *a*, and the pins in the car cable are shown at *a*, view (*b*). To prevent any mistake in the insertion of the jumper, its plug is provided with a projection *c*, which fits into a corresponding gap *d* in the socket. To protect the car-cable socket when not in use, a hinged cover *b* is let down over it.

REQUIREMENTS OF TRAIN CONTROL

43. Connections to Motors.—Just as the motors for tramways and railways were at first very similar, so also the controllers have developed along similar lines in the two cases. The controllers of the form approved for tramway service were therefore adopted for railway working until conditions necessitated radical alterations. Such alterations have not affected the main principle of control, and all the systems about to be described provide for the following operations: (*a*) Motors with resistance are connected in series; (*b*) resistance is gradually cut out; (*c*) motors are connected in parallel, with resistance in series; (*d*) resistance is again gradually cut out.

This method of procedure is, of course, subject to modification where a coach or locomotive is equipped with more than two motors. For example, with four motors the connections may be in the following sequence: (*a*) All in series, (*b*) two sets of two in series, (*c*) all in parallel.

44. Necessity for Multiple Control.—Series-parallel controllers worked by hand are sufficient for small railway systems and industrial locomotives where the currents do not differ much from those which have to be handled on tramways. Heavy railway working, however, calls for special methods of control, as the currents are large and sometimes supplied at high voltages; also in many cases the trains are made up of several motor coaches. It is obvious that, when several coaches in a train are

equipped with motors, the method of control must provide for the management of all the motors from any one point of the train; also the train must be easily divisible, and it should be possible to add other motor coaches which can be operated with the ones previously in use. These requirements led to the introduction of the multiple-unit system of control, by means of which several coaches, each equipped with motors of sufficient power for its own needs, connected together to make up a train, are governed by a master controller. The master controller causes the electromagnetic switches on each motor coach to operate, thus providing the same connections for all the motors.

45. Reversibility of Connections.—An important requirement in multiple-unit systems is the flexibility of the train, and this has great influence on the design of the wiring. It must be possible to turn any coach or any jumper end for end without affecting the control of any of the units of which the train is composed. When a jumper is reversed there must be no change in the relative connections between coaches; the connections both to the reverser and to the contactors on each coach must remain as before. On the other hand, when a coach is reversed, the connections to the reverser must be so changed that the reverser operates in the opposite way and the coach will move in the same direction as the rest of the train. At the same time, the connections to the contactors which control the speed must be unchanged. It is therefore necessary to distinguish between the train wires, which are connected to the reverser and thus determine the direction of motion of the coach, and those which make connection with the contactors and control the speed of the motors. For brevity these wires will be referred to as *reverser wires* and *contactor wires*, respectively.

46. Crossing of Contactor Wires.—In practice, the method usually adopted of disposing the wiring so as to attain the objects stated is to cross the contactor wires in the couplers and in the jumpers and to take the reverser wires straight through both without crossing. Fig. 27 illustrates the method, *a* and *b* representing in plan two coaches and *c* the jumper connecting them. To facilitate the distinction between reverser wires and

contactor wires, the former are indicated by letters *d–e′*, *e–d′* and the latter by numbers *1–1′*, *2–2′*, *3–3′*, *4–4′*, *5–5′*. The effects of the various changes possible in connecting the cars and jumpers are as follows: If the reverser wires *d–e′* are connected to the positive main through the master controller, then the train may be assumed to move in the direction of the arrowheads marked on the uppermost wires, that is, from right to left.

47. Reversal of Jumper.—If the jumper *c*, Fig. 27, is reversed, the connections have the appearance indicated in Fig. 28. In

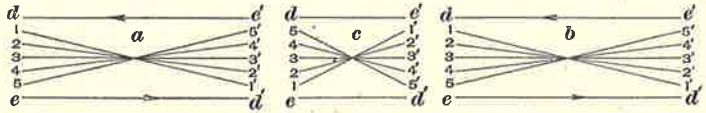


FIG. 27

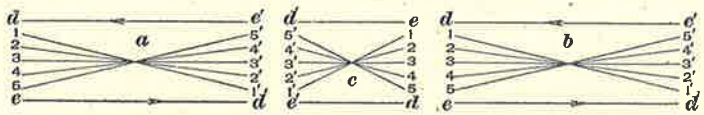


FIG. 28

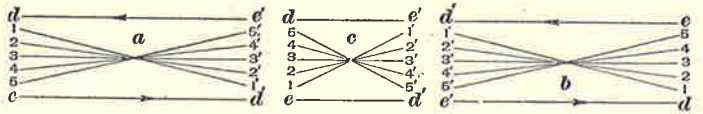


FIG. 29

this case, the connections are identical with those in the previous illustration, and as the contactor wires *1–1′*, *2–2′*, *3–3′*, etc., remain unchanged throughout the train, and the reverser wire *d–e′* of coach *a* connects to wire *d–e′* of coach *b*, therefore the direction of motion of each coach remains the same. It should be recalled that a lug on the jumper fits into a corresponding slot in the coupler, and thus prevents the jumper from being inserted in any other than in the positions indicated in Figs. 27 and 28.

48. Reversal of Coach.—The effect of reversing a coach is shown in Fig. 29, in which the coach *b* is turned end for end.

In this case, current is supplied to the wire d'–e on coach b instead of to d–e'. As a result the coach moves in the direction of the arrow on the line d'–e, that is, in the same direction as the rest of the train, but the direction of motion is toward the end d', $1'$, $2'$, etc., instead of toward d, 1, 2, etc., as shown in Fig. 27. It will be noticed that the contactor connections are unchanged, due to the crossing of the contactor wires on the jumpers and on the coaches.

EARLY MULTIPLE-UNIT SYSTEMS

49. Siemens Mechanical Control.—Among the earliest and simplest of the systems for controlling the motors on a number of coaches was a mechanical method, introduced by Siemens Bros. It consisted of an arrangement of jointed levers extending throughout the whole length of the train, so that the controllers on each motor coach could be operated from the driving end. This method was objectionable because of the mechanical difficulties at the joints between the control rods of the various motor coaches, and was soon abandoned. An electrical method of control presented the best solution of the problem, and is the one invariably used at the present time.

50. Sprague Multiple-Unit Control.—In the first type of the **Sprague multiple-unit control system,** there is on each coach a standard barrel controller actuated through a worm-gear by means of a small pilot motor. The main controller barrels are connected to the worm-wheel shaft by means of a spring, and a cam and pawl are provided so that the controller barrel moves by a succession of jumps, thus quickly breaking the arcs that form at the contact fingers. A number of wires, which are called *train wires*, pass from coach to coach to supply current to electromagnetic switches, which in turn give current to all the pilot motors. The operation of these electromagnetic switches is governed by means of a master controller, which is in the form of a switch with three positions for each direction of running; it also has contacts by which other electromagnets are energized to operate the reversing barrel. In each main controller are the main circuit contacts and seven additional contacts, which

are required for limiting the travel of the controller barrels; these additional contacts are suitably connected in the pilot-motor circuits. An important feature of the system is the automatic relay, which is an electromagnetic switch having its operating coil in series with one motor. Normally this switch is closed; but if the motor current rises above a pre-arranged value, the increase of magnetizing current causes the switch to open, thus breaking the circuit of the pilot motor. The pilot motor is also fitted with an electromagnetic brake, which is held off when the motor is running. When the pilot-motor circuit is opened the brake is applied, and further progress of the main controller is prevented till the current in the main motors falls sufficiently to allow the automatic relay to close the control circuit.

51. Operation of Master Controller.—In the *first* position of the master controller all the reversing barrels are moved to their forward or backward positions; but as the pilot-motor circuits are not completed, the main controller barrels remain in the off-position. In the *second* position of the master controller an electromagnetic switch on each car is closed, and the circuit of the pilot motor is completed through this switch and a contact on the main controller barrel. The pilot motor starts and the main controller barrel is moved forwards at a rate governed by the automatic relay, and when the full series position is reached the circuit of the pilot motor is broken. When the master controller is placed in the *third* position, the pilot-motor circuit is again completed; the main controller barrel now progresses until the full parallel position is reached.

52. Pilot Motor.—The field magnets of the **pilot motor** are wound with two coils, either of which can be connected in series with the armature. In the operations just described only one of these coils is used. If it is desired to turn the main controller barrel back from any parallel position to the full series position, the master controller is moved back to its second position. This operation opens the pilot-motor circuit, but completes it almost instantly through the second field winding; the direction of rotation of the motor is thus reversed, and the main controller

barrel is returned to the full series position. If the master controller is moved from any advanced position to the off-position, the main controller barrels will be returned to the off-positions.

53. Necessity for Unit Switches or Contactors.—An arrangement for operating the various main controllers on a train by means of a master controller is quite suitable where the power is moderate, but an ordinary barrel controller for a pair of 100- or 200-horsepower motors would be very large, and suitable arrangements for effectively suppressing the arcs formed when the circuit is broken at the contact fingers of the controller could not be very conveniently devised. Since a controller is in principle simply a collection of switches, the problem has been solved by separating the switches; and this has given rise to various control systems, in which the switches are opened and closed in the desired order by means of electromagnets, each single switch, or **contactor,** having its own magnet. The operating coils of these electromagnets are connected together by means of train wires, which run the whole length of the train and are tapped off at a number of points by connections to master controllers. Such systems are termed **unit switch,** or **contactor, systems.**

SPRAGUE-GENERAL ELECTRIC TYPE M CONTROL

CONTACTORS, REVERSER, AND CONTROLLER

54. Contactor Groups.—A group of contactors is in principle simply an ordinary controller separated into its component parts, but the separation has been accompanied with modifications to suit the practical conditions of working. All contactors are controlled by electromagnets, for although in the Westinghouse system the contactors are actually worked by compressed air, yet the valves governing the supply of air are worked by electromagnets. It is necessary that contactors open and close with minimum *lag*, or loss of time when the operating circuit is closed. There must be sufficient pressure between the working contacts in order that the contact resistance may be small, and there

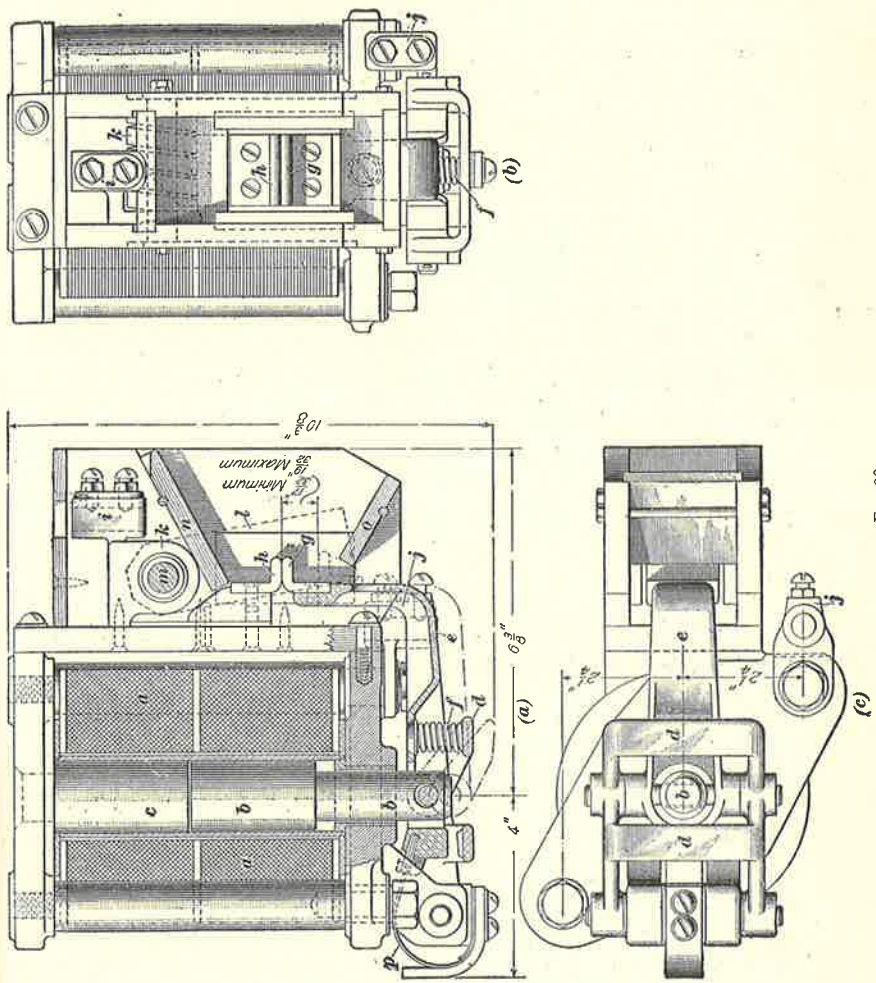


FIG. 30

must also be some device to suppress arcing when the circuit is opened. It is further requisite to construct the contactor in such a way that all parts, especially those most liable to wear, can be easily renewed.

55. British Thomson-Houston Contactor.—One form of contactor used by the British Thomson-Houston and General Electric Companies is shown in Fig. 30, which gives at (*a*) a side-sectional view, at (*b*) a front view, and at (*c*) a bottom view. The operating coil *a* is wound in two sections round the movable core, or plunger, *b* and the corresponding stationary core *c*. On the lower end of the plunger *b* is hinged a frame *d* that presses on arm *e* through spring *f*. Arm *e* carries on its upper end a contact tip *g* that, when the arm is in the position shown, presses against a stationary contact tip *h*, thereby closing any circuit of which they may be a part. One main terminal of the contactor is shown at *i* and the other at *j*. A blow-out coil *k*, consisting of a few turns of heavy bare conductor, is wound round a core *m* to which iron pole pieces *l* are bolted for the purpose of directing a strong magnetic field across the region of tips *g* and *h* and thus suppressing arcing at the contact tips. The arc is driven to the right through a specially provided flue, of which *n* and *o* are the top and bottom walls. The slightly flexible connection *p* is to carry the current from the contact piece *g* to the contactor frame, and thence to the main terminal *j*.

56. The operation of the contactor is as follows: When current from the control circuit passes through the operating coil *a*, plunger *b* is drawn up to the position shown in Fig. 30. At first the frame *d* and arm *e* move together about the pivot, but when tip *g* has come into contact with the stationary tip *h*, further motion of *d* compresses the spring *f*; in this way the contact tip *g* is given a slight rubbing action relatively to *h*, thus ensuring a good contact. The spring also assists the action of gravity in opening the switch promptly and preventing the contacts from sticking when current is cut off from the operating coil.

57. British Thomson-Houston Reverser.—The appliance used in multiple-unit systems for changing the connections to the

motors is called a **reverser.** The reverser is a form of solenoid switch or contactor operated by current from the control circuit through the reversing cylinder of the master controller.

The form of reverser used with the type M system of control is shown in Fig. 31. A cast-iron rocker *a* is hinged at *b*, and on the ends of the beam are two moulded insulation pieces *c*, to which are attached the heavy segments *d*, *d* that carry the main-motor current; segments *e*, *e* are lighter and carry the control current only. Fingers *f*, *f* engage with the heavy segments, and *g*, *g* with the lighter ones. The rocker can be moved through a limited range by means of two solenoids, one of which is shown at *h*; a similar coil is behind *h*, the end of its plunger being shown at *k*. The plungers of the solenoids are connected to the rocker-arm through suitable links, and the movement of the rocker is limited by stops. When coil *h* is energized, the rocker occupies the position shown in the illustration; but when the other coil is energized, the rocker is thrown over to the other position, the left-hand side being pulled toward the base of the reverser and the other side moving down, thus bringing different sets of contacts under the contact fingers. Suitable interlocks make it impossible for both coils to be energized at once. One position of the rocker corresponds to the forward position of the reversing handle on the master controller, and the other to the reverse position.

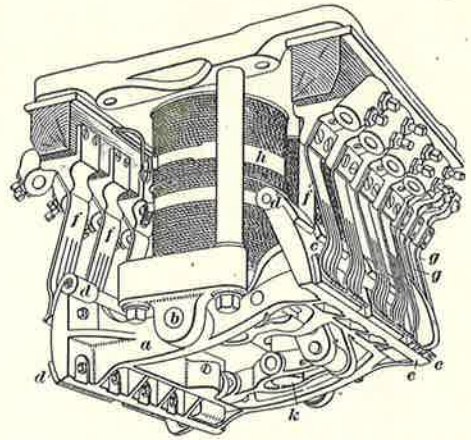


FIG. 31

58. British Thomson-Houston Master Controller.—The master controllers in use with multiple-unit systems of train control

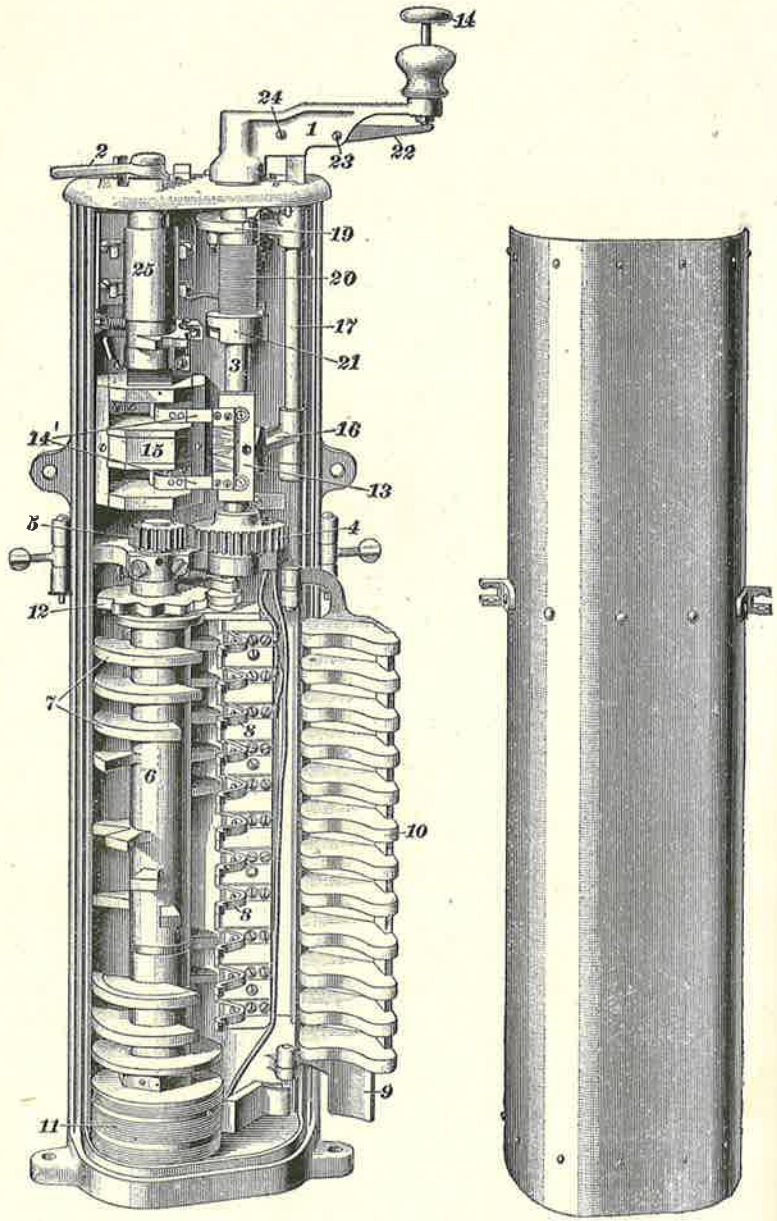


FIG. 32

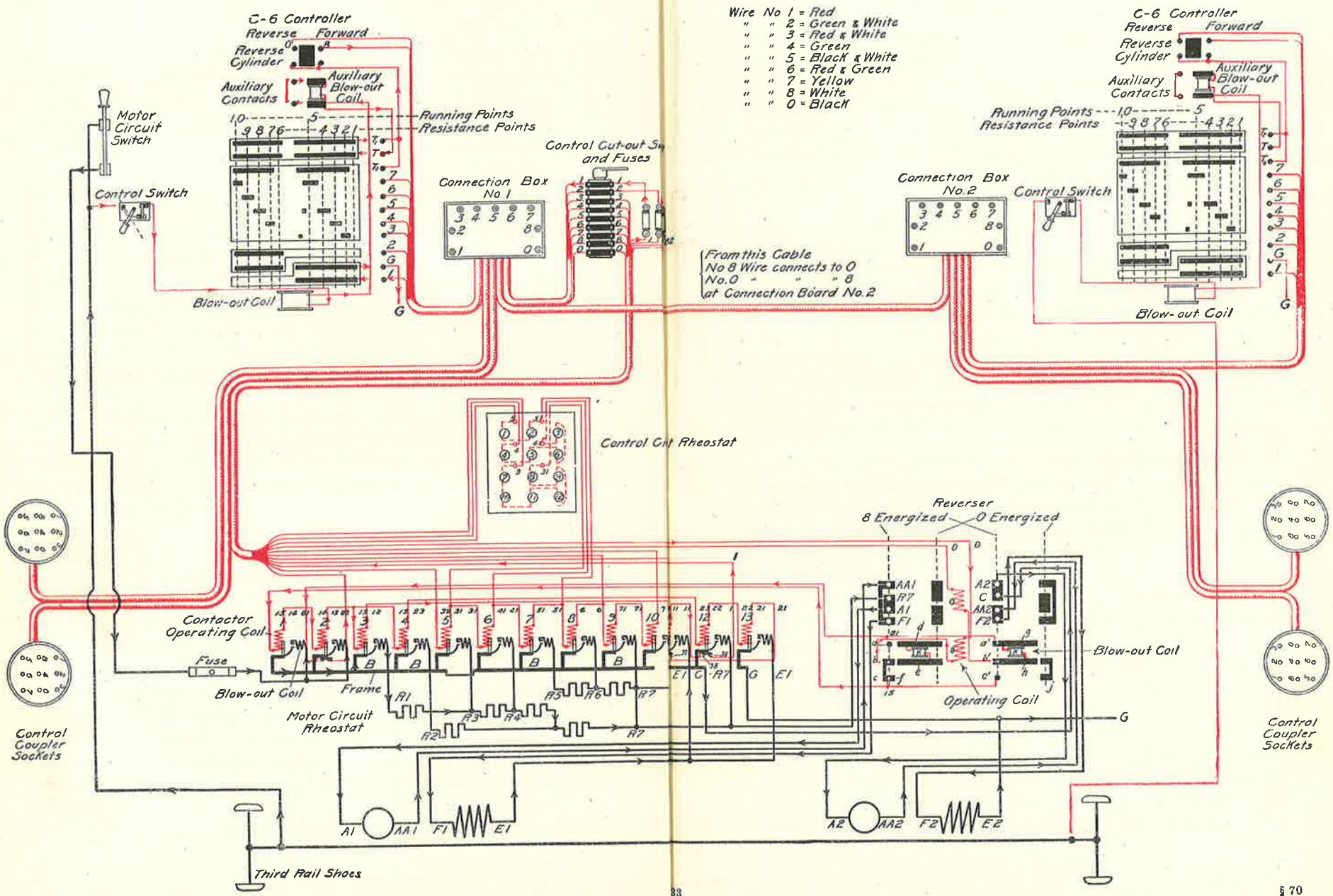
are smaller than the ordinary hand controller used on tramcars. The master controller carries only the current necessary to operate the various contactors, and the reverser of the main or power-control system and the contacts are therefore not designed for heavy service. A view of a British Thomson-Houston type C6 master controller is shown in Fig. 32. The operating handle *1* is not removable, as on an ordinary controller, but the reverse handle *2* is, and when removed the main shaft is locked so that it cannot be turned. The operating handle turns shaft *3*, on the end of which is a gear *4* that meshes with pinion *5* on the shaft of the contact cylinder *6*. The contact cylinder is constructed in the usual manner, except that the contact segments *7* are considerably narrower than on an ordinary controller, the current handled being comparatively small. Contact segments *7* engage with contact fingers *8*, mounted on a terminal board in the usual manner. The iron pole piece *9* carries the insulating arc deflectors *10* that pass between adjacent contact segments whenever the hinged pole piece is swung into its usual position. All current handled by the master controller passes through the blow-out coil *11* and sets up a magnetic field that suppresses arcing at the contacts. The main cylinder is provided with the usual cam-, or index, wheel *12*, which, in connection with a spring-actuated pawl, gives decision to the notches.

59. Dead Man's Handle.—The C6 master controller contains a safety switch *13*, Fig. 32, not usually found on ordinary controllers; it is provided as a factor of safety in high-speed work. To operate the controller and supply current to the motors, it is necessary for the driver to keep knob *14* depressed; if the knob is released, all power is at once cut off from the motors by the opening of safety switch *13*, irrespective of the position of the operating handle; nor can power be applied to the motor circuit again without first restoring the operating handle to the off-position. Should an accident befall the driver, causing him to release knob *14*, the train will be automatically stopped. On this account knob *14* is sometimes called the **dead man's knob or handle.**

60. Operation of Safety Switch.—Switch *13*, Fig. 32, consists of an insulating block on which are mounted two fingers *14'* connected together by a metallic strip. When the switch is closed, the fingers touch contacts mounted in the recesses above and below the auxiliary blow-out coil *15*, which is encased in insulating material. The insulating block that carries fingers *14'*, *14'* is mounted on the end of an arm *16* fastened to the rock-shaft *17*, which is acted on by a spring that normally holds it in such a position that fingers *14'*, *14'* are swung out from their respective contacts. All the current in the operating circuit has to pass through the safety switch, and unless this switch is closed, the control circuit is inoperative and no current can be supplied to the motors. The movements of the rock-shaft *17* and switch *13* are controlled by a cam *19* that has a notch engaging a short arm extending from the rock-shaft; cam *19* is mounted loosely on the main shaft. A spiral spring *20* has its upper end attached to *19* and its lower end to collar *21*, which is firmly fixed to the main shaft *3* and rotates with it.

61. If handle *1*, Fig. 32, is turned, without pressing down knob *14*, the main shaft *3* and drum *6* are turned, but cam *19* does not turn, because it is mounted loosely on the shaft and is prevented from turning by the projecting arm on rock-shaft *17*. Under these conditions, therefore, spring *20* merely twists or untwists, and since switch *13* is not closed, the control circuit is inactive. If, however, knob *14* is pressed down before handle *1* is turned, a small dog, or catch, is pressed down and locks cam *19* to shaft *3*. This dog is forced down by means of lever *22*, hinged at *23*, which engages a second small lever hinged at *24* and mounted within the handle. When cam *19* is thus locked to the main shaft, it forces the rock-shaft *17* to rotate through a small angle just as soon as handle *1* is moved from the off-position, thereby closing switch *13* and allowing current to pass through the controller. Spring *20* is placed in position at the factory under considerable tension, so that there is always a tendency for relative movement between cam *19* and collar *21*. When handle *1* is moved round and knob *14* is pressed down, cam *19* is locked to the shaft and hence moves round with

Car Wiring for ...ague-General Electric Type M Control



Car Wiring for Sprague-General Electric Type M Control

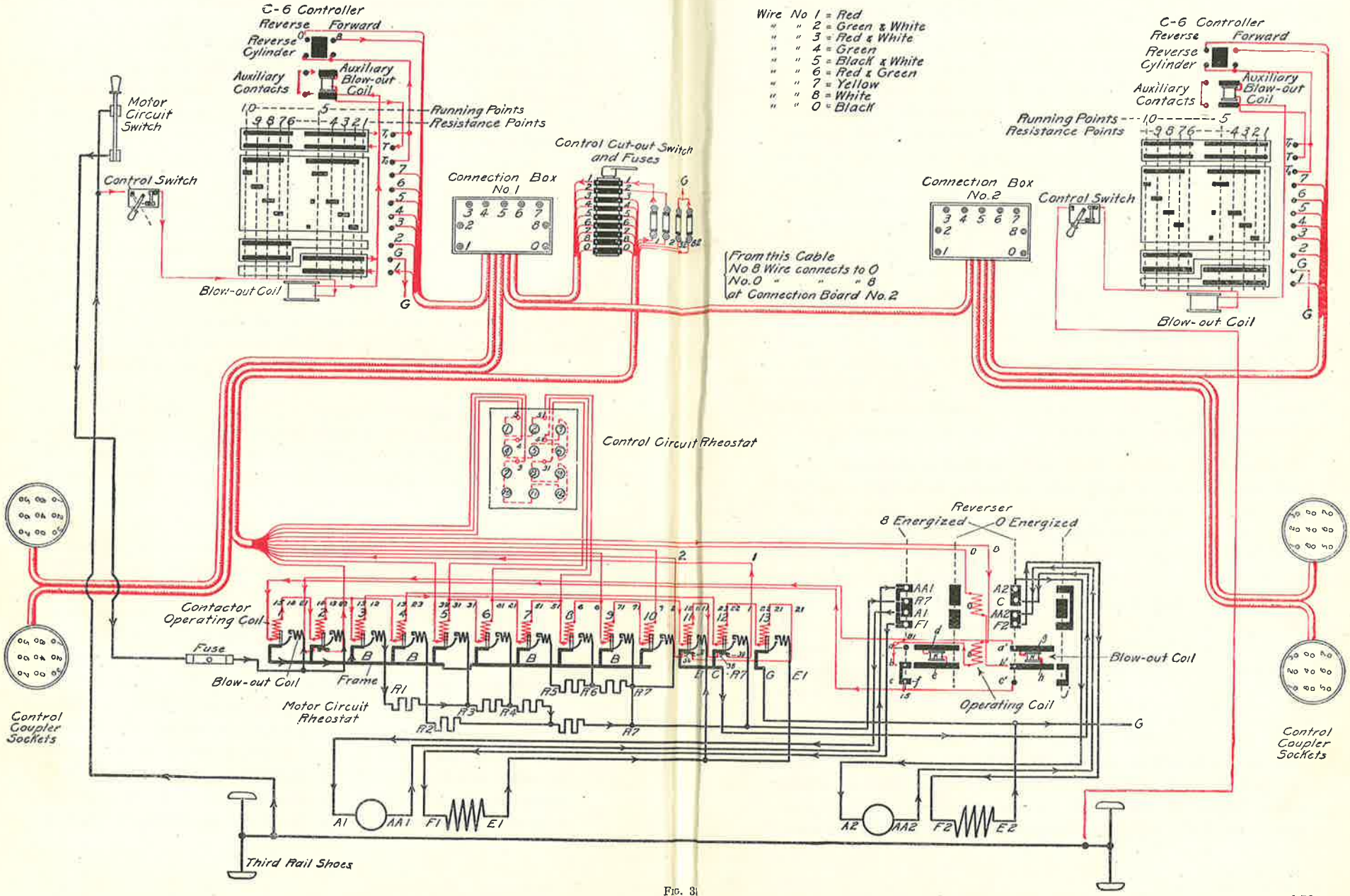


FIG. 3

collar *21*. There is therefore no twisting action on the spring and no change in the initial tension.

62. After the handle *1*, Fig. 32, of the controller has been moved round from the off-position, if the knob *14* is released, the dog engaging cam *19* is released, and *19* is then free to revolve on the shaft independently of the collar *21*. As soon as *19* is released, the tension on spring *20* causes it to fly to its initial position, and switch *13* at once opens, thus cutting off all current from the control circuit. Before the catch operated by *14* can be again made to engage with cam *19*, handle *1* must be brought back to the off-position, thereby restoring the tension in spring *20* to the original amount. The safety device not only cuts off the current in case of accident to the driver, but it prevents current from being thrown on, unless all operating handles are in the starting position. Other forms of dead man's handle have been brought into operation, in which the release of the handle applies the air brakes besides cutting off current from the control circuits. In Great Britain, this device is especially important, as the Board of Trade do not allow a train to be put in charge of only one man unless some such device is installed.

63. Interlocking Device.—The small cylinder *25*, Fig. 32, in the upper left-hand corner of the controller is the reversing cylinder, which controls the movements of the reverser, and thus determines the direction of movement of the car. The handle *2* of the reverse cylinder cannot be removed until it is moved to the off-position, and this motion of cylinder *25* operates an interlocking device that locks the main shaft *3* so that it cannot be moved. The removal of the small reverse handle, therefore, prevents the operation of the car from that controller, so that this small handle in effect constitutes a key to the operation of the train.

TYPE M CONTROL WIRING

64. Connections for Two C6 Master Controllers.—In this system, for two motors, a diagram of which is shown in Fig. 33, type C6 master controllers govern the supply of current to the operating coils of the electromagnetic switches which constitute

the controller for the motors. The latter consists of thirteen switches or contactors, shown at bottom of the diagram, and a reversing switch, generally called a *reverser*. The control-circuit wires are shown in red and the motor-circuit wires in black, in order that each may be readily distinguished. The various operating devices are printed in black irrespective of whether they belong to the control circuit or to the motor circuit. As only relatively small currents are required to operate the switches, the wires passing from car to car are quite small.

At the upper left-hand corner of the diagram is shown one of the small reverse cylinders with the two control wires *0*, *8* connected to its contact fingers. Immediately below the reverse cylinder is the safety switch connected to the dead man's knob or handle. The auxiliary blow-out coil is connected between the two fixed contacts of the safety switch. Below this is the operating cylinder of the master controller, made up of four castings fixed on the same shaft. The black horizontal strips show the development of the contact segments, and all the segments on the same casting are, of course, connected electrically. At the bottom of the operating cylinder is the blow-out coil for suppressing the arcs at the contact fingers, the latter being represented by the vertical row of dots at the right.

65. Reverser Contacts.—The main contacts on the reverser, which is shown at the lower right-hand corner of Fig. 33, are shown by the heavy black bands engaged in pairs by the reverser main-circuit fingers marked *AA1*, *R7*, *A1*, *F1*, *A2*, *C*, *AA2*, *F2*. The operating coil to which wire *8* connects sets the reverser in the position in which the contacts are shown. Introduction of current to the operating coil connected to reverse wire *0* will cause the reverser contacts to shift bodily to the left. Fingers *a*, *b*, *c*, *a'*, *b'*, *c'* and narrow contacts *d*, *e*, *f*, *g*, *h*, *j* have to do with the control circuit, and the purpose of these contacts and fingers will be understood when the operation of the devices is considered. Small magnetic blow-out coils are shown at *k*, *k*.

66. Control Circuit, First Position.—It is assumed that the master-controller reverse cylinder in the wiring diagram, Fig. 33,

is moved to the forward position and that the power handle is moved to the first point, so that the controller contact fingers occupy the position indicated by the vertical dotted line *1*, on the development of the cylinder of the master controller. The coach or train is assumed to be operated from the left-hand controller. As soon as the operating handle is moved from the off-position, the safety switch closes, since the dead man's handle or knob is supposed to be pressed down. The arrowheads show the paths of the control current and main-motor current when the master controller is on the first notch. The path of the control current is then as follows: Third-rail–control switch and fuse–main blow-out coil–auxiliary blow-out coil–auxiliary contacts–finger *T*–finger T_1–finger *8* by way of reverse cylinder –terminal *8* in connection box No. *1*–terminal *8* on cut-out switch–reverser operating coil *8*–reverser control finger *b*–contact segment *f*–finger *c*–*15*–*15*–operating coil of contactor *1*–*14*–*14*–operating coil of contactor *2*–*13*–*13*–operating coil of contactor *3*–*12*–*12*–operating coil of contactor *11*–*11*–*11*–interlock contact *38*–interlock contact *39*–*1*–*1*–fuse *1* near control cut-out switch –cut-out switch *1*–connection-box terminal *1*–operating-cylinder finger *1*–finger *G*–to earth at *G*. On the first point, therefore, contactors *1*, *2*, *3*, and *11* are operated, and the reverser is at the forward position, shown in the illustration.

67. Motor Circuit, First Position.—The path of the motor current when contactors *1*, *2*, *3*, and *11*, in Fig. 33, are closed and the reverser is in the forward position is: Motor-circuit switch–main fuse–$<$contactor *1*, contactor *2*$>$–frame *B*–contactor *3*–*R1*–*R3*–*R4*–*R7*–*R7* (on reverser)–*A1*–*A1*–*AA1*–*AA1* (on reverser)–*F1*–*F1*–*E1*–*E1* (on contactor *11*)–*C*–*C* (on reverser)–*A2*–*A2*–*AA2*–*AA2* (on reverser)–*F2*–*F2*–*E2*–earth at *G*.

Contactors *1* and *2* are connected in parallel so as to reduce the current handled by each, because these contactors correspond to the trolley fingers of an ordinary controller, and the service imposed on them is more severe than on the others. Contactors *9* and *10*, which come into use on the last series and last parallel notches, are connected in a similar manner.

68. Operation of Reverser.—In tracing the control circuit when the master controller is on the first point, it was assumed that the reverser already occupied the position shown in Fig. 33 and corresponding to that assumed when reverser operating coil *8* is energized. Suppose, however, that the reverser had, on account of previous use or for any other reason, occupied the opposite position, so that the small interlock fingers on the reverser rested on segments *d*, *e*, and *j* instead of *g*, *h*, and *f*. The current entering the reverser on wire *8* would then take the path through operating coil *8*–finger *b*–segment *e*–blow-out coil *k*–segment *d*–contact finger *a*–*81*–*81*–interlock on contactor *2*–*82*–*82*–fuse or control cut-out switch–earth at *G*. There can be no current in the motor circuit because contactors *1* and *2*, called *line contactors*, are not closed. By the action of the current in coil *8*, the reverser is thrown over to the requisite position. Then the operation proceeds as previously described. Blow-out coils *k*, *k* suppress all arcing that tends to follow the interruption of the control current.

69. Controller on Other Series Positions.—As the contact cylinder of the master controller is turned to positions *2*, *3*, and *4*, Fig. 33, contactors *5*, *6*, and *7* are added to those already in operation, as can be seen by tracing out the control circuit. The result is to reduce the resistance in series with the motors. On the fifth position, which is the last series notch and one of the running notches, all the starting resistance is cut out. The path of the control current is as follows, starting from finger *T* on the master controller: *T*–T_1–T_0–finger *7*–connection-box terminal *7*–cut-out contact *7*–coil of contactor *10*–*71*–*71*–coil of contactor *9*–*6*–*6*–coil of contactor *8*–*51*–*51*–coil of contactor *7*–*41*–*41*–coil of contactor *6*–*31*–*31*–coil of contactor *5*–*32*–*32*–fuse near control cut-out switch–earth at *G*. The path of the reverser control current remains as before, so that it is not necessary to trace it out.

Contactors *1*, *2*, *3*, *5*, *6*, *7*, *8*, *9*, *10*, *11* are closed, thus short-circuiting all the resistance, so that the circuit through the two motors in series is: Motor-circuit switch–fuse–$<^{\text{contactor } 1}_{\text{contactor } 2}>$–frame *BB*–$<^{\text{contactor } 9}_{\text{contactor } 10}>$–*R7*–*R7*–*A1*–*AA1*, etc.–ground. All the resistance is cut out and the two motors are in series.

70. Operation on Parallel Positions.—When the operating drum of the master controller is on position *6*, Fig. 33, that is, the first parallel notch, the path of the operating current from finger *T* is as follows: *T*–T_1–reverse cylinder–*8*–*8* in connection box–*8* on cut-out switch–coil *8* on reverser–*b*–*c*–*15*–*15*–coil of contactor *1*–*14*–*14*–coil of contactor *2*–*13*–*13*–coil of contactor *4*–*23*–*23*–coil of contactor *12*–*22*–*22*–coil of contactor *13*–*21*–*21*–interlock *37*–*36*–*2*–fuse *2*–*2* on cut-out–*2* on connection box–finger *2* on controller–earth at *G*. This keeps the reverser in the position that it already had on the series notches, and operates contactors *1*, *2*, *4*, *12*, and *13*.

In parallel circuits each path is indicated by the reference letters in the columns under the brackets. The joining of two or more columns by a bracket at the bottoms indicates that the circuits unite to form a single path.

The path of the motor current is then as follows:

Motor circuit switch–fuse–

contactor *1*–	contactor *2*–

B–*B*–contactor *4*–*R2*–*R7*–

R7 (on reverser)–*A1*–*A1*–*AA1*–*AA1*–*F1*–*F1*–*E1*–contactor *13*–	*R7* (on contactor *12*)–contactor *12*–*C*–*C*–*A2*–*A2*–*AA2*–*AA2*–*F2*–*F2*–*E2*–

earth at *G*.

The motors are therefore in parallel with two sections of the resistance in series with the circuit.

71. When the controller drum is placed in position so that contactors *5* and *6*, Fig. 33, operate, they reduce the resistance in the circuit by placing a resistance section in parallel with one of the sections previously inserted. On the eighth position, contactor *7* is closed and resistance sections *R5*–*R6*–*R7* are

placed in parallel with those already in use. On the ninth position, contactor *8* is closed and resistance section *R5–R6* is short-circuited. On the last parallel notch, contactors *9*, *10* are closed, thus giving a direct connection between cable *B* and the wire *R7* running to the reverser.

On the parallel notches, the resistance in series with the motors is decreased by connecting sections in parallel rather than by cutting out existing sections. The advantage of this method is that, as the resistance is reduced, its current capacity is increased, and it is better able to carry the heavy current taken by the car on the parallel notches.

72. Summary of Operations.—As far as the final effect on the motors is concerned, the combinations effected by the movement of the master controller are practically the same as those effected by an ordinary series-parallel controller, though the master controller itself is not connected with the motors. In Table I is given a list of the contactors in operation for each position of the master controller.

TABLE I

ORDER IN WHICH CONTACTORS CLOSE

Number of Notch	Contactors in Operation
1	1 2 3 11
2	1 2 3 5 11
3	1 2 3 5 6 11
4	1 2 3 5 6 7 11
5	1 2 3 5 6 7 8 9 10 11
6	1 2 4 12 13
7	1 2 4 5 6 12 13
8	1 2 4 5 6 7 12 13
9	1 2 4 5 6 7 8 12 13
10	1 2 4 5 6 7 8 9 10 12 13

In Fig. 33, the connections have been explained by referring to the operation of devices on one car only. Where a number of cars are coupled together, the devices on all cars are operated synchronously by the currents in the train cables.

AUTOMATIC CONTROL

73. British Thomson-Houston Automatic Control.—In order to secure uniform acceleration of electric trains and prevent undue strain on the apparatus, some control systems are provided with **throttle relays** or **limit switches,** which are electromagnetic devices that open the control circuit when the main current reaches too great a value, and thus regulate the rate at which the contactors successively close. By the use of the throttle relay the handle of the master-controller can be moved at once to the full parallel notch, and the master-controller cylinder will follow step by step as it is allowed by this device.

Instead of the controller cylinder being positively driven by the spindle to which the operating handle is attached, it is connected to it by means of a spring, and a magnetically operated lock prevents the cylinder from following the movement of the operating handle so long as the current taken by the motors exceeds a predetermined amount. The device thus ensures the greatest possible acceleration without slipping of the wheels or injury to the apparatus. This type of control has been installed on the North Eastern Railway at Newcastle-upon-Tyne.

74. Automatic-Relay Control. — A system of multiple-unit control, similar to the type M, but having the throttle-relay feature, has been developed by the General Electric Company, and is known as the **automatic-relay control.** Each contactor is fitted with special auxiliary contacts in addition to those which carry the main current of the motors. These auxiliary contacts are utilized for the purpose of controlling the operating coil of one or more of the other contactors in such a way that the whole series of operations just described is carried on automatically, the switches closing in succession as the train accelerates, until the connections correspond to the position of the handle of the master controller. As in the case of the semi-automatic system on the North Eastern Railway, the rate at which the contactors are successively closed is independent of the rate at which the control handle is moved, but is determined by the limit or throttle switch.

75. Construction of Relays.—The main features of the throttle relay used with the Sprague-General Electric type M automatic-relay system are shown in Fig. 34. The relay consists of an iron core fixed to an iron framework, and a movable core, or plunger, which helps to complete the magnetic circuit. Coil *b* is energized by the current supplied to one motor, and current from the control circuit passes through the coil *a* and through the contacts *c* and *d* by way of the disc. Blow-out coils *e* extinguish the arcs formed at *c* and *d* when the contact is broken. The top of the plunger is connected to a small piston, which works in a cylinder at the top of the relay; the cylinder is provided with adjustable throttle valves which control the rate at which the plunger rises.

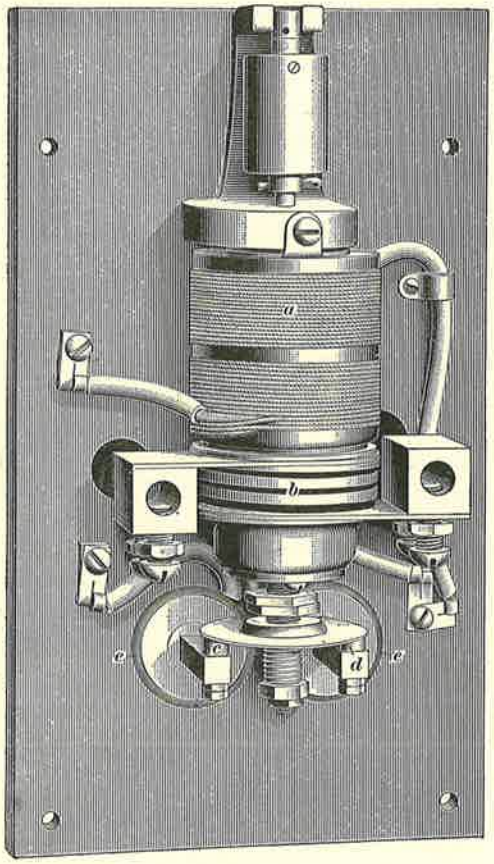
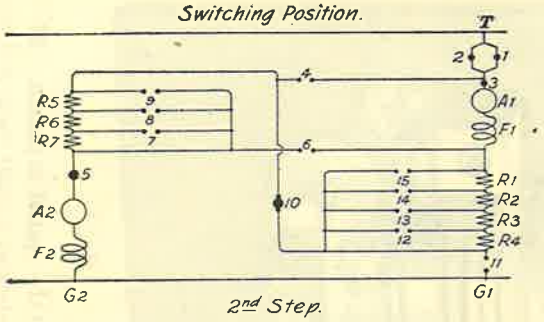


FIG. 34

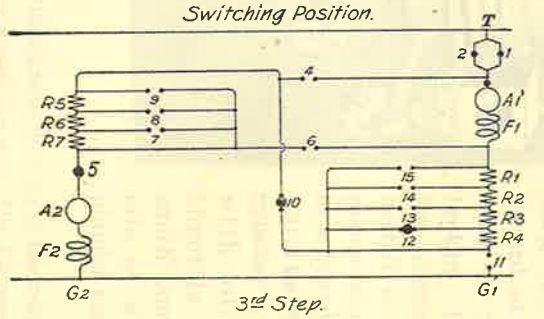
76. Action of Relay.—If the current flowing in the main-circuit coil *b* is more than a predetermined amount, the plunger and its disc are lifted up, thus breaking the control circuit and preventing further progress of the control apparatus until the motor current has fallen sufficiently to allow the plunger and disc to drop.

Series.

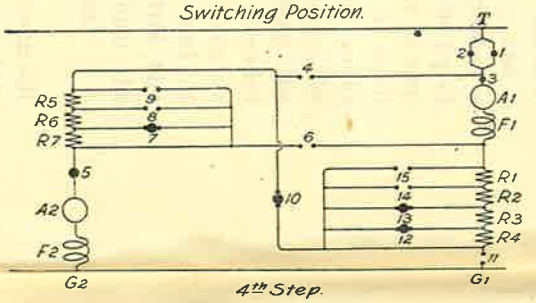
1st Step.
Switching Position.



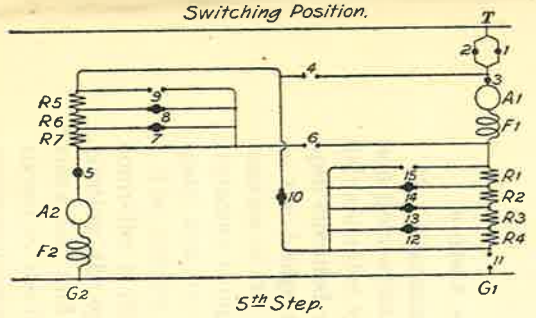
2nd Step.
Switching Position.



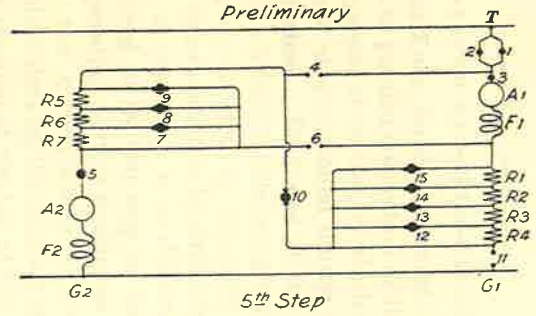
3rd Step.
Switching Position.



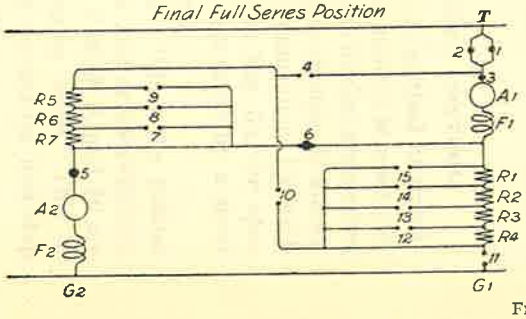
4th Step.
Switching Position.



5th Step.
Preliminary

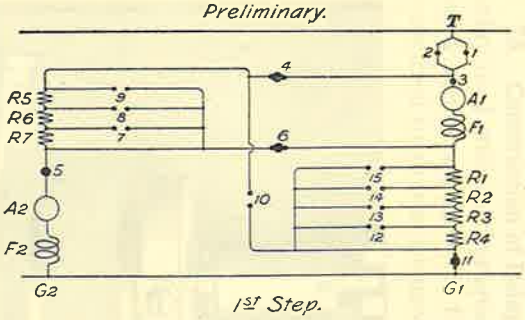


5th Step
Final Full Series Position

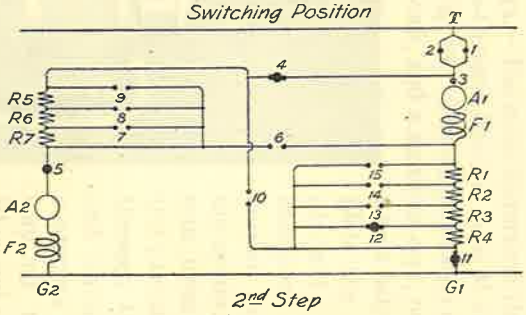


Parallel.

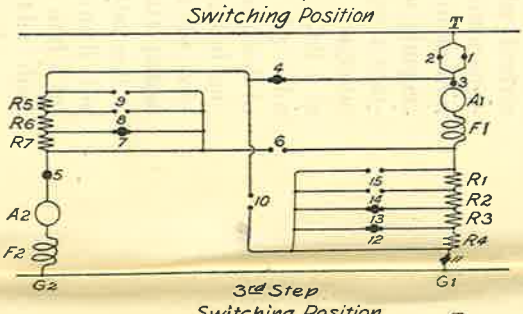
1st Step.
Preliminary.



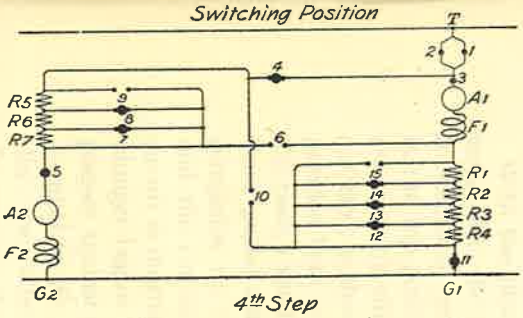
1st Step.
Switching Position



2nd Step
Switching Position



3rd Step
Switching Position



4th Step
Full Parallel Position

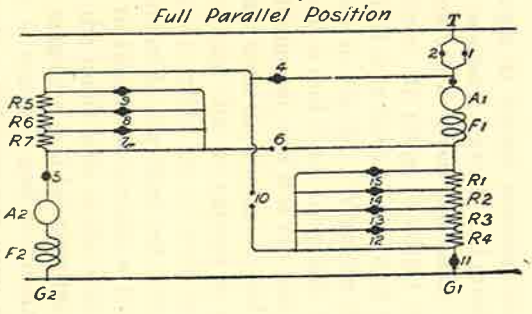


FIG. 35

With the plunger at lowest position there is a large air gap included in the magnetic circuit, and greater magnetizing force is needed to produce a given pull than when the plunger is in the top position. In order to adjust the pulls so that they are properly effective in both positions of the plunger, two coils are used, as shown in Fig. 34. When the plunger is in the lowest position both coils *a* and *b* are energized, but when the plunger has risen a small amount, coil *a* is cut out of circuit by the disc being pulled away from the contacts *c* and *d*. The plunger then completes its motion due to current in coil *b* only. The disc and the contacts *c* and *d* are of iron, and this local magnetic circuit is magnetized by the blow-out coils *e*, *e*. Now, when the plunger begins to rise, it compresses a spring, the top of which presses against the under side of the disc. When this pressure is equal to the magnetic pull between the contacts *c*, *d* and the disc, the latter is released and so breaks the circuit of coil *a*. To prevent the disc and contacts from sticking, their surfaces are coated with a layer of non-magnetic metal.

BRIDGE SYSTEM OF SERIES-PARALLEL CONTROL

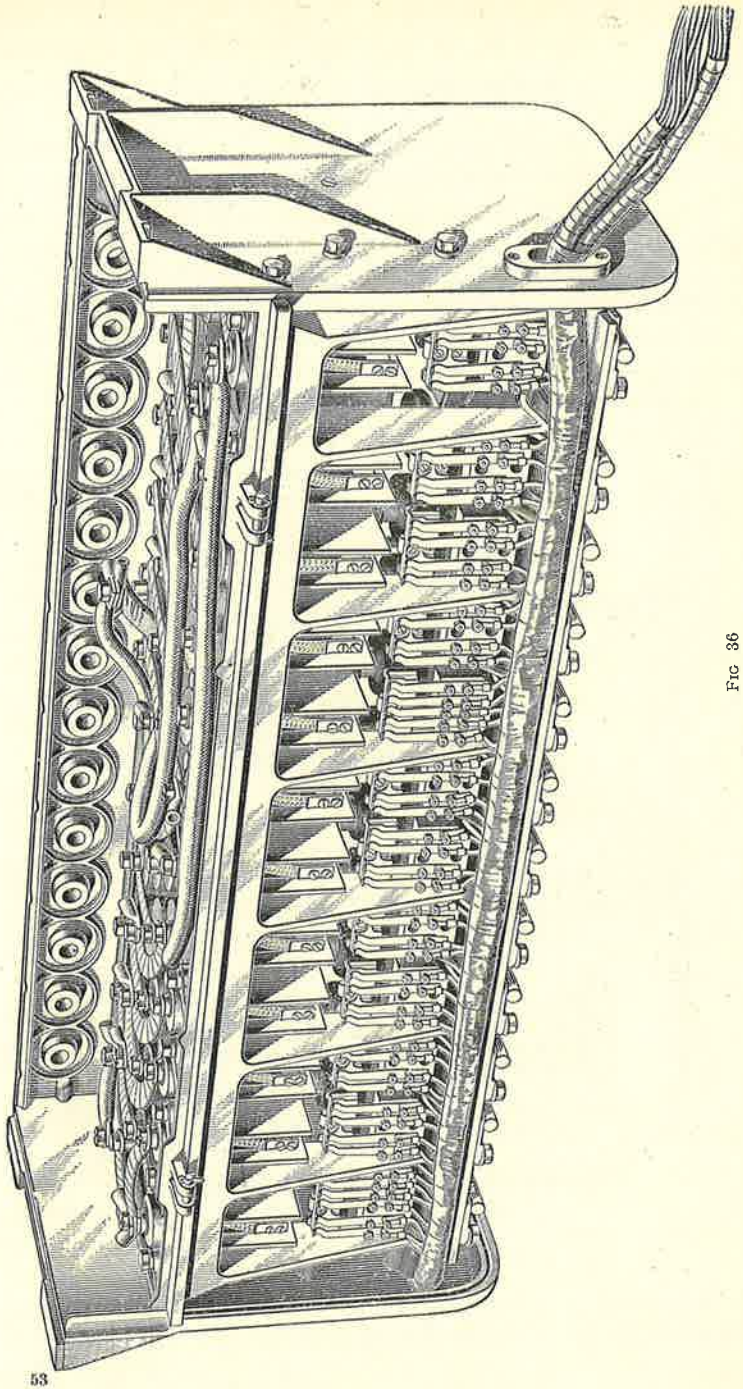
77. Transition From Series to Parallel.—A method of transition from series to parallel connection of the motors in multiple-unit and other systems of control, by which the motors are neither open-circuited nor short-circuited during the change, is known as the **bridge system.** Diagrams of the connections for each position of the controller handle are given in Fig. 35, the *open contactors* being represented by two dots separated by a short space, and the *closed contactors* by single dots.

The method of operation is as follows: When the master controller is moved to its first step or the first series-switching position, the operating coils of contactors *1*, *2*, *3*, *5*, and *10* are energized and the corresponding contactors close. This is shown by the black dots on the diagram of circuits for first-step series-switching position at the top of Fig. 35.

Current flows from *T* on the positive main through contactors *1* and *2–3*–armature *A1*–field *F1*–resistances *R1–R2–R3–R4*–switch *10*–resistances *R5–R6–R7*–switch *5*–armature *A2*–field

F2–to earth at G_2. The motors are therefore in series with all the resistances. On the next position, second step, the resistance contactor *12* is closed, and on succeeding steps up to the full series position contactors *7* and *13*, *8* and *14*, and then *9* and *15* are closed in the order of enumeration at a rate determined by the limit switch, thus gradually cutting out the resistance. In the final full series position contactor *6* closes, and the opening of interlocks on this contactor breaks the circuit of the operating coils of contactor *10* and of the resistance contactors *7*, *8*, *9*, *12*, *13*, *14*, *15*. The path of the current is now from *T* on positive main–contactors *1* and *2–3–A1–F1*–contactors *6–5–A2–F2*–earth at G_2. The motors are thus connected in series without any resistance in series with them.

78. On the first-step parallel or preliminary switching position, see Fig. 35, current is supplied to the operating coils of contactors *4* and *11*, the closing of which opens the circuit of the operating coil of contactor *6*. It will be seen that the effect of the first of these operations is to connect the resistances in series across the mains from *T* through contactors *1* and *2–4–6–11* to earth at G_1 and G_2. If the resistances are suitably designed, the current taken by them will be equal to that taken by the motors in full series, and in that case the current in each motor will be unchanged by the closing of contactors *4* and *11*, but the current through contactor *6* will be reduced to nothing. Under these conditions, the motors are in parallel, one being in series with resistances *R1–R2–R3–R4* and the other with resistances *R5–R6–R7*, and contactor *6* opens sparklessly. On the succeeding positions of the master controller, as shown in the various diagrams, Fig. 35, resistance is cut out as before by the successive closing of the resistance contactors until the motors are in full parallel. During the transition the current in each motor is not appreciably altered, and thus there is no sudden variation of tractive force, and therefore no jerk during the acceleration period. A further advantage is that no arcs are formed at the contact surfaces of the contactors because the circuit is not broken, except when the motors are switched out of circuit in order to stop the car.



53

FIG 36

WESTINGHOUSE ELECTRO-PNEUMATIC CONTROL

CONTACTORS AND CONTROLLER

79. Principle of Action.—In the **Westinghouse unit-switch system** compressed air is used to operate the contactors by means

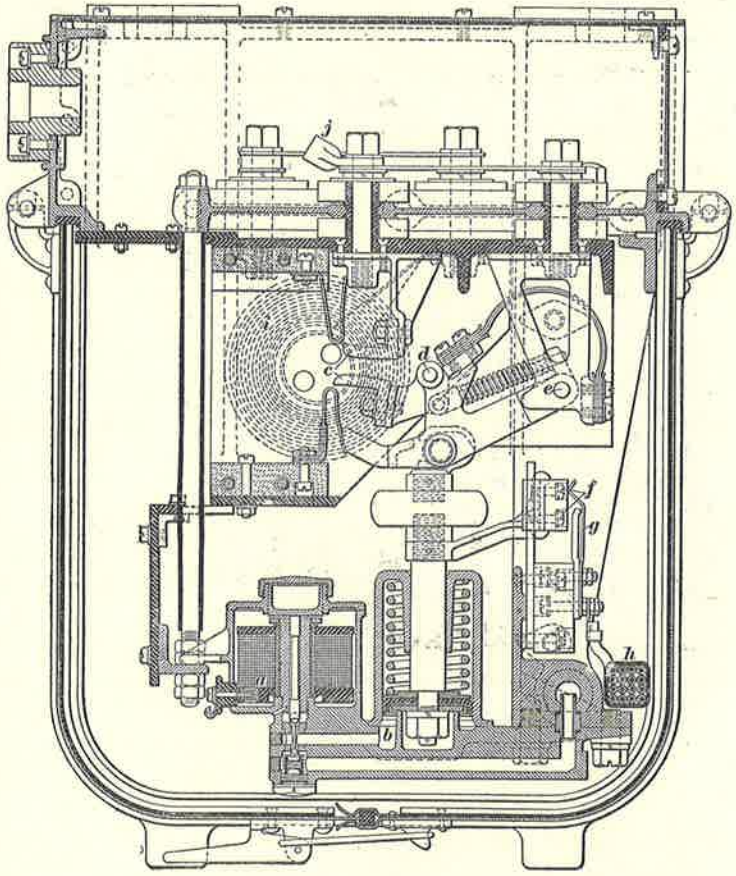


FIG. 37

of small valves worked by electromagnets. A storage battery is installed on the train for the purpose of supplying current to

these electromagnets, the supply being regulated by the driver through the agency of the master controller. The battery consists of fourteen cells arranged in two sets of seven cells each, the connections being such that, while one set is being used, the other is being charged. It is thus unnecessary to connect several magnets in series, as in the Sprague system, in which current for energizing the contactor magnets is taken direct from the line. The control in the unit-switch system is automatic, the rate of switching on being governed by a limit, or throttle, switch. Most of the contactors are provided with double-wound electromagnets, the two windings being insulated from each other. One winding serves to close the contactor and the other to hold it closed.

80. Electro-Pneumatic Contactor. — A Westinghouse unit-switch group in which a number of contactors are arranged in line on a frame is shown in Fig. 36, and a sectional view of a single unit switch is shown in Fig. 37. When the operating magnet *a*, Fig. 37, is energized, it opens a valve and allows air, under a pressure of about 70 pounds per square inch, to enter the lower portion of the air cylinder *b*, thus forcing the piston upwards and closing the main contacts *c*. The support of the movable switch contact is pivoted to the switch arm at *d*, and the arm is pivoted at *e* to the frame, thus, when the switch closes, giving a rubbing action, which is an aid in securing good contact. On opening the circuit of the operating valve, the air valve closes,

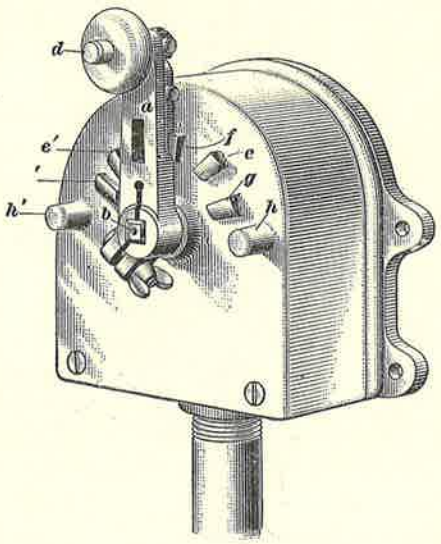


FIG. 38

the air cylinder *b* exhausts to the atmosphere, and the piston is forced downwards by a spring, thus separating the contacts *c*.

81. Interlocks and Blow-Out Coils.—On the piston rod which operates the main contactor is an arm carrying a block on which are mounted the interlock segments, one of which is shown at *f*, Fig. 37. The interlock segments make or break contact with fingers, one of which is shown at *g*, and which are connected to wires in the control cable *h*. To suppress the arc formed on breaking the main circuit at the contact *c*, a blow-out coil *i* is provided. As in the contactor previously described, current passes from the lower contact to a terminal on the frame through a flexible connector, while the insulated terminal *j* is in connection with the upper contact. It is worthy of note that the normal position of the switch is open, so that a failure of air supply or interruption of the control circuit opens all the switches. Similar switches have been combined together in a different way, namely, by arranging them radially round a common blow-out coil. This arrangement, known as the *turret controller*, was installed on the Metropolitan Railway but found to be unsuitable, and so was replaced by the arrangement shown in Fig. 36.

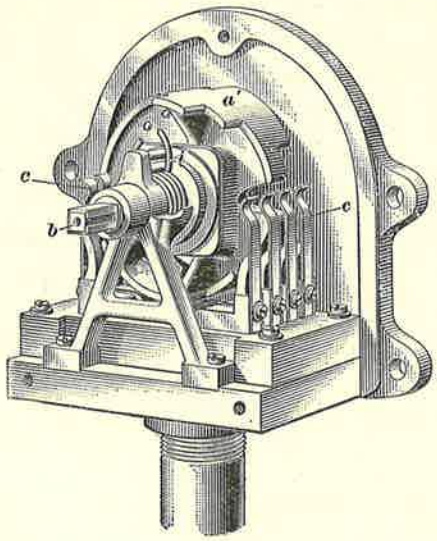


FIG. 39

82. Master Controller. One form of master controller used with the Westinghouse unit switch is shown complete in Fig. 38, and with the cover removed in Fig. 39. The operating handle *a*, Fig. 38, is shown in the off-position of cylinder *a'*, Fig. 39. The cylinder *a'* consists of a single metal spider mounted on a horizontal shaft *b*, the turning of which causes

the cylinder to engage fingers *c*, *c*. The operating handle *a*, Fig. 38, can be placed in position only when the controller cylinder is at the off-position, and to rotate the handle, pin *d* must be depressed, thus raising a small lever *f* that interferes with lugs *e*, *g*, *h* or *e'*, *g'*, *h'* cast on the cover. A movement of the operating handle to the right corresponds to a forward motion of the car or train, and a movement to the left reverses the motion. If the operating handle is moved to the position marked by lug *g*, the circuit combinations will automatically change until the motors are in full series across the line. As long as the operating handle is kept in this position, the combinations will not change, but an advance to the position marked by lug *h* will automatically change the combination until the motors are in parallel across the line. If the handle is released at any stage of its operation, spring *i*, Fig. 39, will return it to off-position, in which all circuits are automatically interrupted.

UNIT-SWITCH CONTROL WIRING

83. Wiring Diagram.—The diagram of connections for two Westinghouse master controllers used in connection with a unit-switch group to control two motors is shown in Fig. 40. The master-controller cylinders are indicated near the upper corners of the diagram, the three positions of the contact fingers being indicated by the dotted lines numbered *1*, *2*, *3*. The control circuits are indicated in red and the motor circuits in black, but contacts on all apparatus, whether for the control or the power circuits, are indicated in black. Contactors or unit switches *1* and *2*, *11* and *3*, *9* and *10*, *4*, *12*, and *13* always close or open in groups, so a single operating coil is provided for each group. In the description of the action of the control system, the controller at the left of the diagram is assumed to be in use. The interlocks for any unit switch are placed vertically over the switch.

84. Interlock Connections.—Some of the contactors in the Westinghouse unit-switch systems are provided with auxiliary contacts or interlocks, consisting of fixed contacts indicated in Fig. 40 by black dots or vertical strips, and movable contacts

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indicated by horizontal black lines. The latter are connected with the main switches in such a way that, when the main switch closes, the movable contact or interlock arm moves downwards. In switches *7* and *12* the interlock closes when the main contact opens, but in the remaining contactors, excepting *13*, both interlock and main switch open and close together. Contactor *13* is provided with a double set of contacts so as to close one circuit when open and another when closed. Contactors *4* and *5* are special in construction. In each of them, when the main switch is open, the interlock arm makes contact with the two right-hand strips; soon after it has started its downward stroke it makes contact with the third strip, and just before the end of the down stroke it makes contact with the left-hand strip and disengages with the right-hand strip. The interlocks prevent the unit switches from closing in any but the proper order, and in conjunction with a line switch or overload circuit-breaker make the system of control automatic.

85. Control Circuit, First Forward Position.—Movement of the master-controller handle, Fig. 40, to its first forward position establishes connections as follows: Master-controller finger $B+$, connected to the positive battery terminal, connects to fingers *5S* and *1* through the master-controller cylinder. Assuming the line-switch cut-out to be closed, the path is: Finger *5S*–*5S* on line-switch cut-out–terminal *5*, junction box *1*–*5*, box *2*–coil *5* on line switch–line switch or circuit-breaker contacts, called in diagram *C.B.* trip–negative battery wire $B-$. Excitation of coil *5* closes the line switch *C T* by admitting air to its operating cylinder. The closing of the line switch provides a trolley connection at *T*, and allows current to flow from a point near contactor *12* through the resistance *C* and lifting coil of the line relay to earth *G*, thereby closing the line relay, the contacts *8* and *S* of which are in parallel with the line-switch interlock *8*, *S*. The line-switch interlock is always open when the switch is closed. Simultaneously, a current from finger *1* passes through reverser coil *1* and thence to the negative side of the battery. This current opens the valve controlled by reverser coil *1*, and if the reverser is not already in the forward position, it will promptly move to this position.

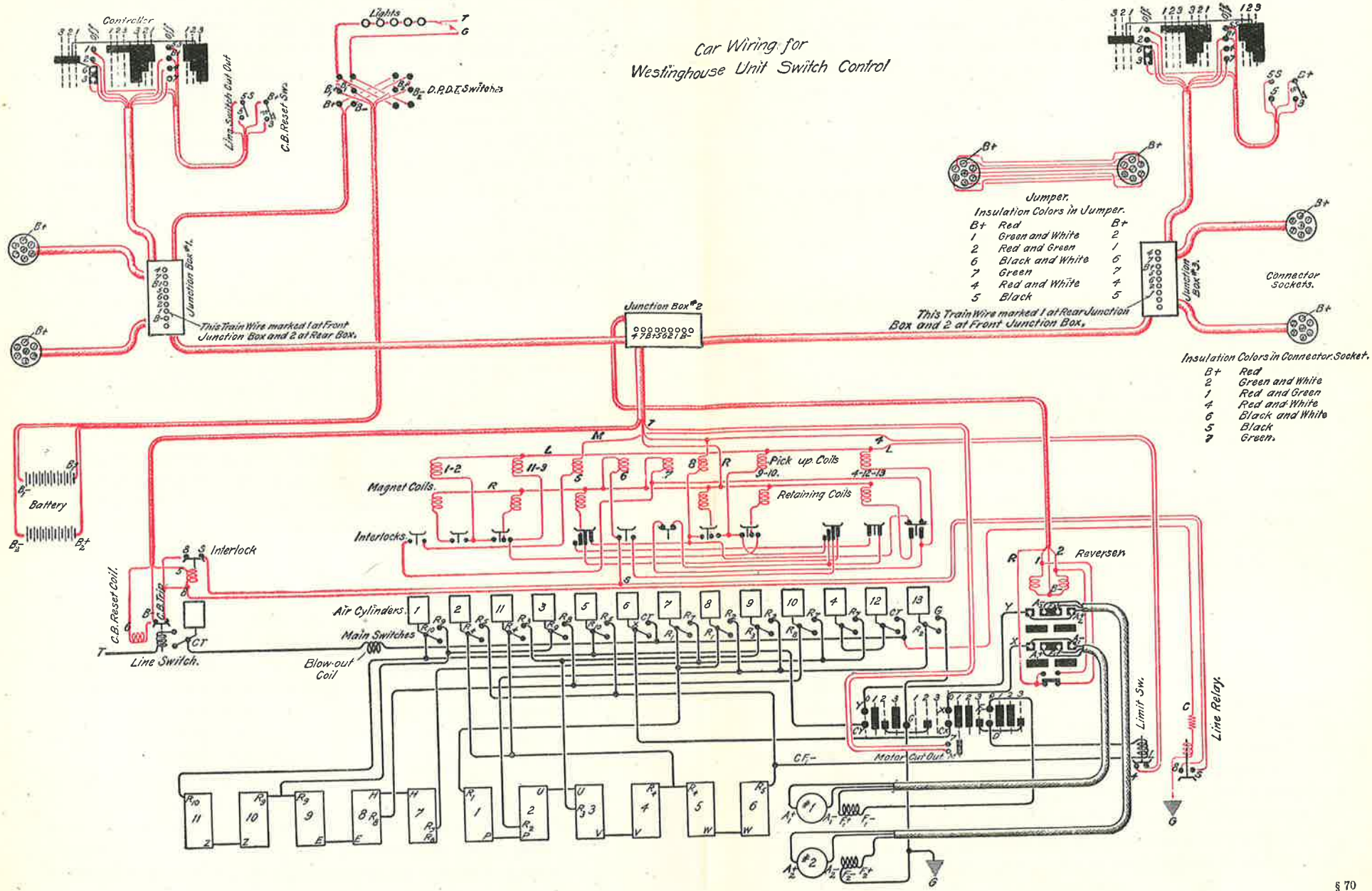

Car Wiring for
Westinghouse Unit Switch Control
Controller
Lights
T
G
D.P.D.T. Switches
Line Switch Cut Out
C.B. Reset Sw.
Junction Box #1.
This Train Wire marked 1 at Front Junction Box and 2 at Rear Box.
Junction Box #2
Jumper.
Insulation Colors in Jumper.
B+ Red
1 Green and White
2 Red and Green
6 Black and White
7 Green
4 Red and White
5 Black
B+ Red
2
1
6
7
4
5
This Train Wire marked 1 at Rear Junction Box and 2 at Front Junction Box.
Junction Box #3.
Connector Sockets.
Insulation Colors in Connector Socket.
B+ Red
2 Green and White
1 Red and Green
4 Red and White
6 Black and White
5 Black
7 Green.
Battery
Magnet Coils.
Interlocks.
Pick up Coils
9-10.
4-12-13
Retaining Coils
Interlock
C.B. Reset Coil.
C.B. Trip
Line Switch.
Air Cylinders.
Main Switches
Blow-out Coil
Reverser
Limit Sw.
Line Relay.
Motor Cut Out
#1
#2

FIG. 40

As soon as the reverser has moved the full length of its travel, the safety switch shown just below it establishes connection between wire *1*, which is connected to the positive battery wire $B+$, and wire R, which represents the positive sides of the retaining coils *1–2*, *11–3*, *5*, *8*, *9–10*, *4–12–13*, and the pick-up coils *6* and *7*.

86. The reverser must be fully thrown forwards or back, otherwise its safety switch will not connect wire R, Fig. 40, to the battery. Assuming the reverser to be at the extreme end of its travel, wire R will become $B+$, and current flows from R–pick-up coil *6*–S–line-relay contacts *S–8–8* on line switch –*C.B.* trip contacts–$B-$, thereby operating unit switch *6* and closing its interlock. The closing of this interlock causes current to take path R–pick-up coil *7*–upper interlock contacts of unit switch *13*–right-hand contacts of interlock of switch *5* and of interlock of switch *4*–contacts of interlock of switch *6*, here joining with the current from pick-up coil *6* and flowing with it through the line-relay contacts to $B-$, and thereby operating unit switch *7*. The motors are now in series with resistance, as will be seen by tracing out the main-current path, assuming the line switch and unit switches *6* and *7* to be closed.

87. Full Series Position.—On moving the master controller to the second position, thereby connecting controller finger *4*, Fig. 40, to $B+$, current flows out on wire *4*–pick-up coil of switch *8*, which closes switch *8*–interlocks of switches *5*, *4*, and *6*–S and with the operating currents of switches *6* and *7*, through the line-relay switch to $B-$. A branch of wire *4* connects through the limit switch to wire L, which is the positive side of the pick-up coils of unit switches *9–10*, *11–3*, *1–2*, and *4–12–13*. The closing of the interlock of switch *8*, due to the operation of unit switch *8*, has given a $B-$ connection to retaining coil *8* and also to the pick-up coil *9–10*, which closes switches *9* and *10*. The closing of switch *9* gives its retaining coil a $B-$ connection through its own interlock and interlocks of switches *8*, *5*, *4*, and *6*. The operation of unit switch *9* also gives a $B-$ connection to pick-up coil *11–3*, which immediately causes unit switches *11* and *3* to close. These switches are held closed by their retaining coil, which gets its $B-$ connection through interlocks *11*, *9*, *8*, *5*, *4*,

and *6*. The closing of unit switch *11* closes its interlock, through which a *B*— connection is given to pick-up coil *1–2*, which causes switches *1* and *2* to close. These switches are then held closed by their retaining coil getting a *B*— connection through interlocks of switches *2*, *11*, *9*, *8*, *5*, *4*, and *6*. The motors are now in full series across the line, all the resistance being cut out by the closing of switches *8*, *9–10*, *11–3*, *1–2*.

88. Full Parallel Position.—On moving the master controller to the third position, finger *B*+, Fig. 40, is connected to wire *7* and battery current takes the path : *7*–motor cut-out interlock–wire *M*–pick-up coil *5*–interlocks of switches *1*, *13*, *5*, *4*, *6*–*S*–*B*—, by way of the line relay, as in preceding cases. The closing of switch *5* first completes the circuit of its own retaining coil through the middle contacts on interlock *5*–interlock *4*–interlock *6*–*B*—, as usual. Toward the end of the piston stroke, the sliding contact on interlock *5* breaks connection with the right-hand contact, thereby depriving the pick-up and retaining coils *7*, *8*, *9–10*, *11–3*, and *1–2* of their negative or *B*— connections and causing these switches to open. When switch *5* is fully closed, the short contact of its interlock completes the circuit through the pick-up coil *4–12–13* as follows: *B*+ *4*–*L*–pick-up coil *4–12–13*–interlock on switch *7*–interlock on switch *12*–interlock on *5*–interlock on *4*–interlock on *6*–line relay–*B*—. Switches *4*, *12*, and *13* do not close until switch *7* has fully opened, because interlock *7* is part of the circuit through pick-up coil *4–12–13*, and this interlock is closed only when its unit switch is entirely open. When switch *13* closes, a negative or *B*— connection to the retaining coil is established through the lower interlocks of switch *13* and the interlocks of switches *7–12–5–4* and *6*. In the first part of the downward movement of the piston of switch *4*, its interlock engages the low contact, thereby establishing another *B*— path through the middle fingers of the interlock of switch *4*. The first path is broken in two places by operation of unit switches *4* and *12* when these switches are nearly closed, and the *B*— connection of the retaining coil of switch *5* is also broken. Unit switch *5* is in use only during the transition from series to parallel connection of the motors.

89. The effect of the various combinations formed in the control circuit is to connect the motors in parallel, but having five sections of resistance in series with each. The contactors in the unit-switch group, Fig. 40, which are closed are *6*, *4–12–13*. The full closing of switch *4* connects the short contact of its interlock to *B*—, thereby providing a *B*— connection for the pick-up coil of the *9–10* magnet, which causes switches *9* and *10* to close. The closing of switch *9* causes the consecutive closing of *11–3* and *1–2*, thus connecting the motors in full parallel.

DICK-KERR CONTROL SYSTEMS

MULTIPLE-UNIT CONTROL

90. Dick-Kerr Contactor.—A view of the **Dick-Kerr contactor** is shown in Fig. 41. The contactors are arranged in groups of four, each group being placed in an iron box. In the illustration, *a* is the iron supporting frame, *b* the operating coils, *c*, *c′* are the switch contacts, and *d* the insulating supports for the switch parts. The lower end of the plunger may be seen at *e*, and the upper end, which is not shown, carries the contact *c′*. The contact *c* is hinged and kept down by a spring, so that when *c′* is pressed upwards by

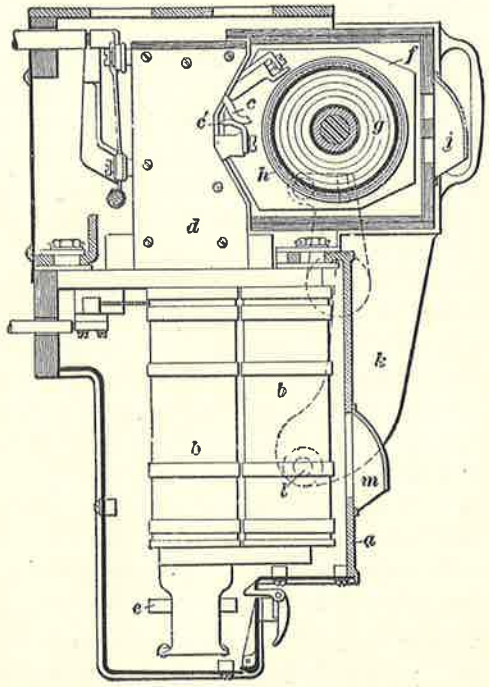


FIG. 41

the pull on the plunger a slight rubbing action takes place between the contacts, and this helps to keep them clean and to give good contact. Ventilation is provided for by the two openings j and m, air being drawn in at the lower opening and expelled at the upper one.

When current is cut off from the operating coils, the contact between c and c' is broken simply by the action of gravity. As the operating coil carries the current of one motor and thus requires few turns, its inductance is low, and therefore the contactor is very prompt in action. The inductances of two coils, one wound with fine wire of many turns and the other with thick wire of few turns, are quite different even when the effective magnetic pulls given by the two coils are the same. The reason for this is because the inductance varies as the square of the number of turns. It is possible, therefore, by using a heavy controlling current for the contactors, to secure prompt action.

91. Metallic-Shield Blow-Out.—The contactors in one group are separated by partitions f, Fig. 41, which effectually prevent the arc from passing from one pair of contacts to those adjacent. The blow-out coils g for each group are mounted on a common iron rod and supported by the carrier k. The rod on which the coils are mounted is not large enough to materially affect the magnetic field, so that the field effective for blowing out arcs may be taken as proportional to the current flowing. The blow-out coils are provided with non-magnetic metal casings, or shields, h, which come very near to the tips of the contacts. When the circuit is broken by the opening of the contacts c, c', the arc passes to the shield h and is forced outwards by the magnetic field toward the opening j and broken. The final break of the arc occurs at some point on the shield h, and tests have shown that the shield is uninjured and the main contacts are entirely relieved of the arc. Because of the action of the magnetic field in breaking the arc on the shield h, the arrangement just described is known as the **metallic-shield blow-out.**

92. Dick-Kerr Master Controller.—The master controller used with the Dick-Kerr multiple-unit system is provided with three

distinct contact cylinders, or barrels, A, B, and C, as shown in Fig. 42. The barrel A, called the **switching barrel,** is connected directly to the operating handle. On this barrel are mounted the contacts which close the by-pass circuits through the operating coils of the reversers and contactors. The barrel which operates the contactors is called the **contactor barrel;** it is mounted immediately below the switching barrel, and is operated by means of a lug a, which is moved by a cam b at the bottom of the switching barrel A. The cam b is shaped so as to allow the switching barrel to move through a certain angle before the contactor barrel is moved. The object of providing this free movement of the switching barrel is to allow the control coils to become demagnetized and the contactors to open by the time the operating handle reaches the off point. The operating handle is fitted with a mechanical lock which permits the barrels A and B to be moved one step at a time. Before the handle can be advanced from one notch to the next, a slight backward movement is necessary. The **reversing barrel** is indicated at C, and is provided with a small reversing handle c so that it can be turned to make the proper connections to the operating coils of the reversers. In every case the main circuits are broken at the contactors and not at the controller fingers, so blow-out coils are not necessary.

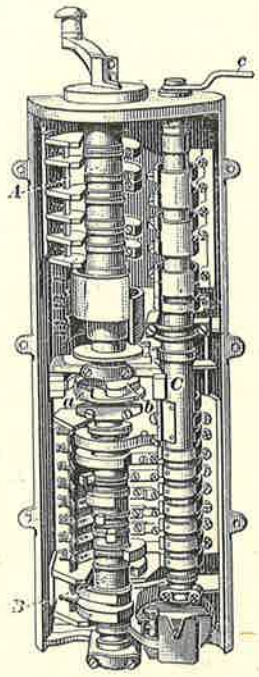


FIG. 42

93. Principle of Operation.—In the Dick-Kerr multiple-unit system supplied to the Lancashire & Yorkshire Railway, all the contactors except those for the reversers are operated by the current flowing to one of the driving motors, and not by a separate control circuit as in the systems previously considered.

To start the motors, the controller handle is turned so that the by-pass switches *a*, Fig. 43, are closed, and the two-way switch *b* disconnected from the earth at G_1 and turned to the lower contact. Current flows from the collector shoe *c* through the motors d_1 and d_2 and solenoids *e* to earth at G_2. Directly the solenoids are excited, they close the contacts *f*, so that it is unnecessary to keep the by-pass switches *a* closed, and they can be opened sparklessly. By joining other solenoids in parallel with *e*, *e*, as indicated by the dotted lines, and governing the flow of current by a suitable controller, other contactors or switches can be arranged to cut out sections of resistance and to connect the motors in parallel.

94. Wiring Diagram.—A diagram of the connections of the Dick-Kerr multiple-unit controller to the car wiring is shown

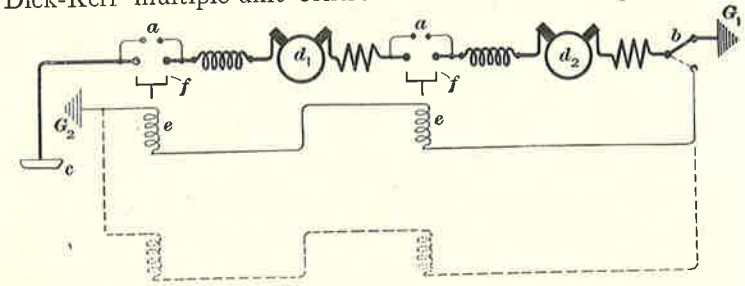


FIG. 43

in Fig. 44. In order to simplify the connections, the operating coils of the contactors and reversers are shown at one side, though their true positions under their contactors are indicated by numbers and letters corresponding to the coils. The contactors are lettered and numbered the same as the coils.

The switching barrel *A* of the controller can move through an angle corresponding to the distance *a b* before the contactor barrel *B* begins to move. At the base of the controller there is a small magnet coil *d* which, when excited, locks the contactor barrel. The reversing barrel is shown at *C*, the positions of the fingers for forward and backward running being marked.

95. Circuits on Series Positions.—In order to start the motors, the reversing barrel *C*, Fig. 44, is turned to the forward position, so that the two rows of contact fingers, which are shown as

black dots, occupy the positions indicated by the lines *e* and *f*, or to the backward position, so that the fingers are at the positions indicated by the lines *e* and *g*, and the operating handle is turned until both switch and contactor barrels are in position *1*. If the reverser fingers are in the forward positions *e* and *f*, current flows as follows: Collector shoe *h*–circuit-breaker *i*–fingers *j1*, *j* on switch barrel *A*–fingers *k*, *k1* on reversing barrel *C*–armature *A1*–fingers *k2*, *k3* on reversing barrel–field *F1*–resistances *R1*, *R2*–fingers *l8*, *l9* of contactor barrel–magnetic lock coil *d*–fingers *j3*, *j4* on switch barrel–fingers *k4*, *k6*, on reversing barrel–armature *A2*–fingers *k5*, *k7*, on reversing barrel–field *F2*–resistances *R3*, *R4*–fingers *j6*, *j7* on switch barrel–

fingers *l*, *l1* on contactor barrel–contactor operating coil *1*–coupler *m*–contactor operating coils *n*–

fingers *k9*, *k10* on reversing barrel–reverser operating coils

8a | *8b* | *8c* | *8d*

coupler *m*–reverser operating coils *n*–

earth at G_2.

The couplers *m* are between the motor coaches and the operating coils or control magnets *n* are on the other motor coach. Contactor *1*, Fig. 44, is closed by the action of operating coil *1*; this short-circuits the locking magnet *d* and permits the contactor barrel to be moved forwards. Contactors *8a*, *8b*, *8c*, and *8d* on the reversers are also closed, and current flows in the following circuit: Collector *h*–*i*–contactor *8a*–armature *A1*–contactor *8b*–field *F1*–*R1*–*R2*–contactor *1*–contactor *8c*–armature *A2*–contactor *8d*–field *F2*–*R3*–*R4*–fingers *j6*, *j7* on switch barrel–

fingers *l*, *l1* on contactor barrel–operating coil *1*–coupler *m*–operating coil *n*–

fingers *k9*, *k10*, on reversing barrel–reverser coils

8a | *8b* | *8c* | *8d*

coupler *m*–operating coils *n*–

earth at G_2.

When the contactor barrel *B* is moved to position *2*, the first section *R1* of the resistance is short-circuited by the closing of contactor *2*, the circuit being as follows: *h*–*i*–*8a*–*A1*–*8b*–*F1*–*2*–*R2*–contactor *1*–contactor *8c*, and so on as before.

As the contactor barrel *B* is moved to positions *3*, *4*, and *5*, the other sections of the resistance are successively short-circuited, until in position *5* the motors are in full series, the circuit being the same as before, except that all the resistance sections are short-circuited by the closed contactors *2*, *3*, *4*, and *5*.

96. Circuits on Parallel Positions.—During the transition of the contactor barrel *B* from position *5*, Fig. 44, to position *6*, contactors *3* and *5* are first opened, putting all resistance in series with the motors, then contactor *6* is closed, thus short-circuiting motor *1* through *R1* and *R2*, until contactor *1* is opened and opens the circuit of motor *1*. The magnetic lock-coil is connected to finger *l9* of the contactor barrel, and is therefore out of circuit in the parallel positions of the contactor barrel, so that contactor *1* can be opened without locking the barrel. Contactor *6* closes the circuit through the operating coil of contactor *10*, and contactor *10* closes. When the contactor barrel reaches position *6*, so that finger *l7* makes connection, contactor *7* is closed and motor *1* is connected directly to earth, all the control circuits being excited by the current through motor *2*. Contactors *6*, *7*, *8a*, *8b*, *8c*, *8d*, *10* are closed, and the circuit is as follows: Collector shoe *h* – circuit-breaker *i*–*m'*–

contactor *8a*–*A1*–contactor *8b*–*F1*–*R1*–*R2*–contactor *10*–contactor *7*–earth at G_3.

contactor *6*–operating coil *10*–contactor *8c*–*A2*–contactor *8d*–*F2*–*R3*–*R4*–*j6*–*j7* on switch barrel–

l–*l6*, *l7*–operating coils *6* and *7*–coupler *m*–operating coils *n*–

k9, *k10*–operating coils

8a | *8b* | *8c* | *8d*

coupler *m*–operating coils *n*–

earth at G_2.

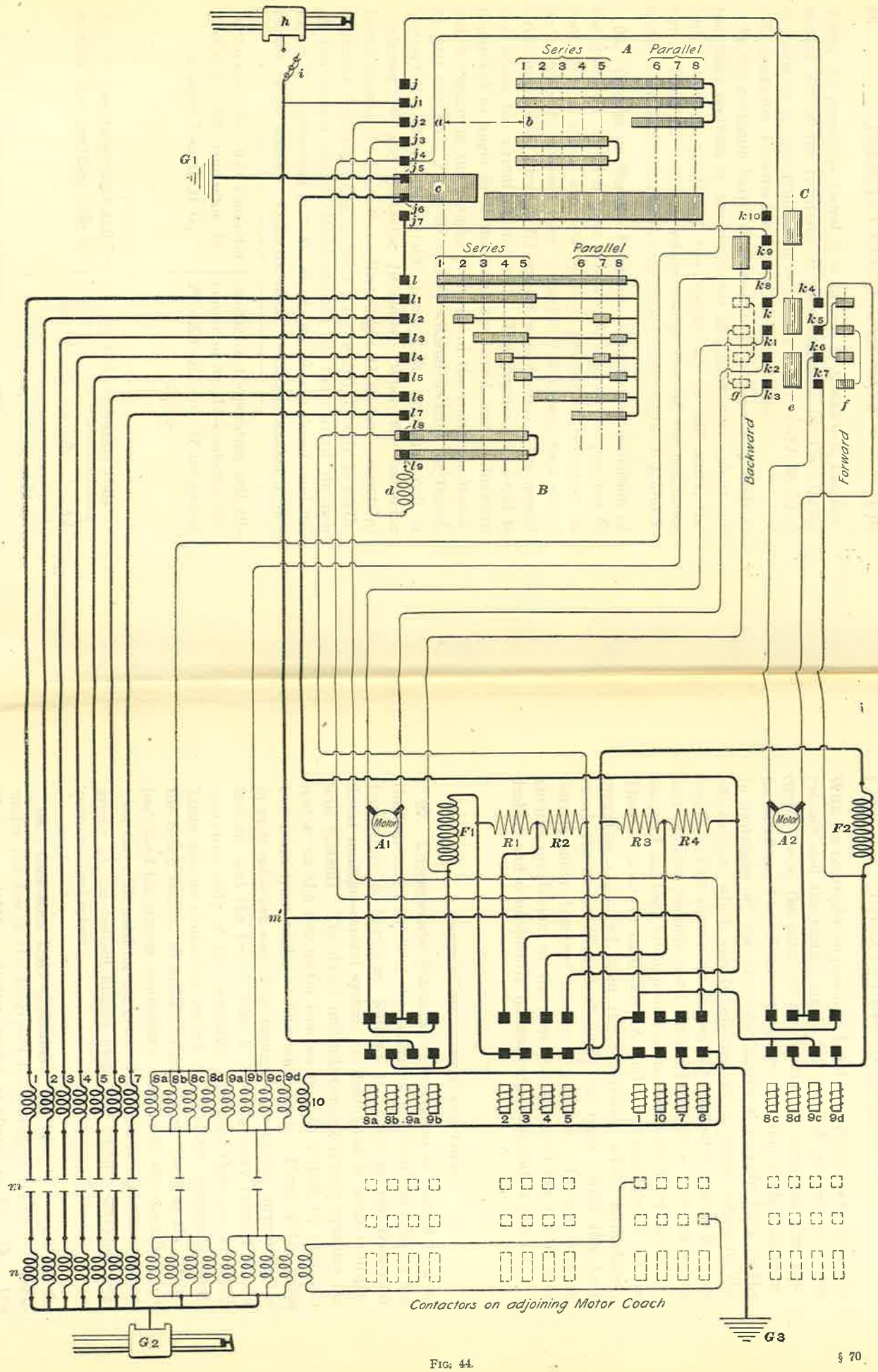
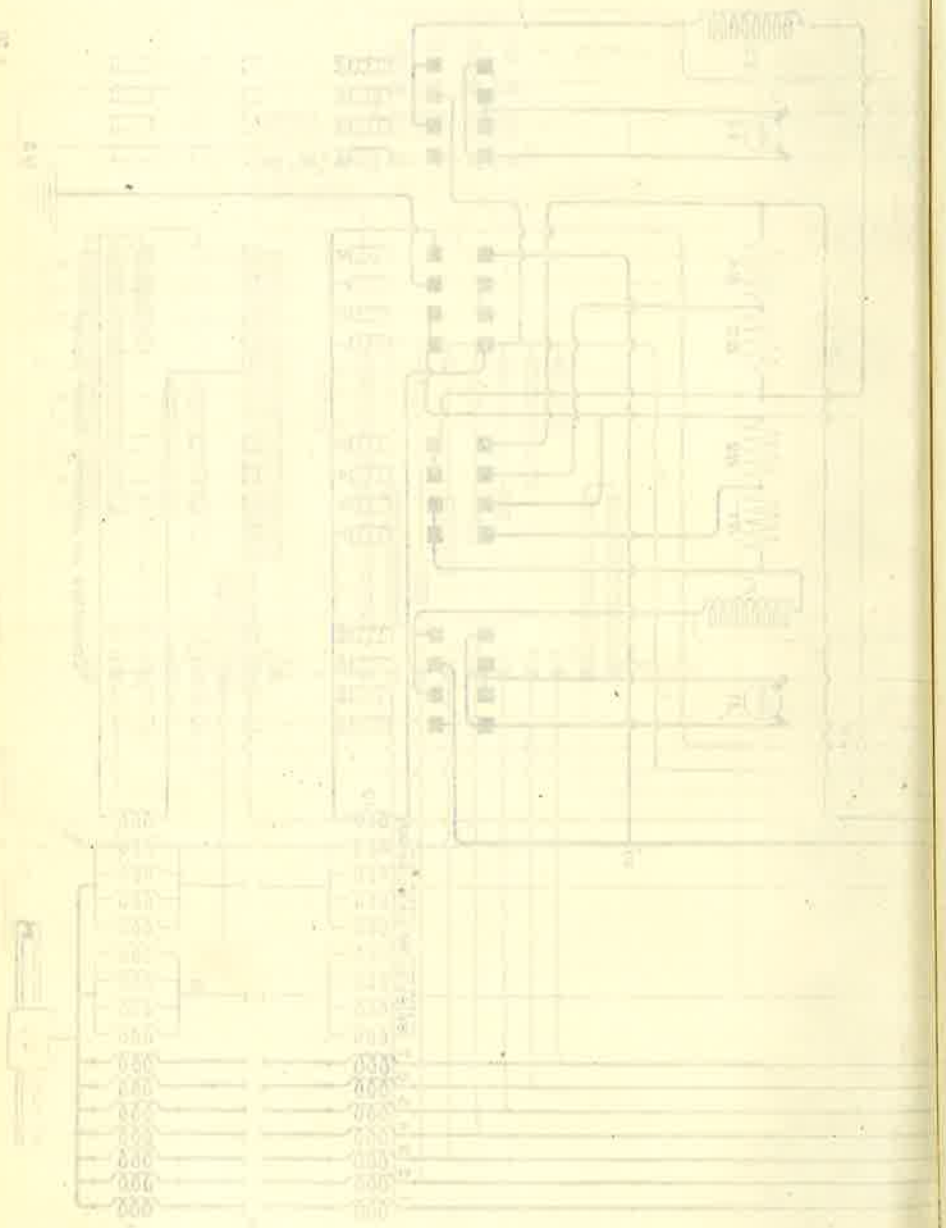

h
i
G1
Series
A
Parallel
1 2 3 4 5
6 7 8
j
j1
j2
j3
j4
j5
j6
j7
a
b
c
C
k10
k9
k8
k
k1
k2
k3
k4
k5
k6
k7
g
e
f
Backward
Forward
Series
Parallel
1 2 3 4 5
6 7 8
l
l1
l2
l3
l4
l5
l6
l7
l8
l9
d
B
i
Motor
A1
F1
R1
R2
R3
R4
Motor
A2
F2
m
1 2 3 4 5 6 7
8a 8b 8c 8d 9a 9b 9c 9d
10
8a 8b 9a 9b
2 3 4 5
1 10 7 6
8c 8d 9c 9d
m
n
Contactors on adjoining Motor Coach
G2
G3

FIG. 44.

§ 70



With the controller on positions *7* and *8*, resistance is successively cut out and the motors are in full parallel on-position *8*, the circuit being the same as for position *6*, excepting that contactors *3* and *5* are closed, thus short-circuiting all the resistance. In switching off, the controller handle is brought back to the off-position, which can be effected by a single sweep of the handle. This movement leaves the contactor barrel *B* in its first parallel position, until the earthing sector *c* on the switch barrel *A* has been brought into connection with fingers *j5* and *j6*. These connect to earth at *G1*, and thus short-circuit all the operating coils and open the contactors, which immediately break the motor circuits all along the train. After this, both barrels move together to the off-position. In this way no circuits are broken at the contactor barrel of the master controller, and consequently no magnetic blow-out is needed.

DIRECT MULTIPLE CONTROL

97. Characteristic Features.—The system of control used on the four-coach trains of the Liverpool and Southport line of the Lancashire & Yorkshire Railway is known as the **Dick-Kerr direct multiple-control system,** to distinguish it from multiple-unit systems. The direct multiple-control system operates the motors on the two motor coaches used in a train by means of two main train cables of four wires each. Three of the wires in each cable are each large enough to carry the current for the motors, and the fourth wire is used to carry current to the operating coils of the reversers, and may therefore be small. There are no contactors except the reverser contactors under the coach bodies, all other contacts being made at the control barrels of the master controllers. Owing to the metallic-shield blow-out coils used on the controllers, it is possible to eliminate arcing at the contact fingers when the circuits carrying large currents are broken.

98. Dick-Kerr DM4 Controller.—In the cab of each of the motor coaches of the Liverpool to Southport trains is a **Dick-Kerr type DM4 controller,** which is shown in Fig. 45. The

controller has two contact cylinders a, a', one being provided to control the motors of each of the two motor coaches of each train. If the train has but one motor coach, only one of the contact cylinders will be in use. The two cylinders are geared together and are operated by one handle b. The frames containing the insulating partitions c, c', which fit between the

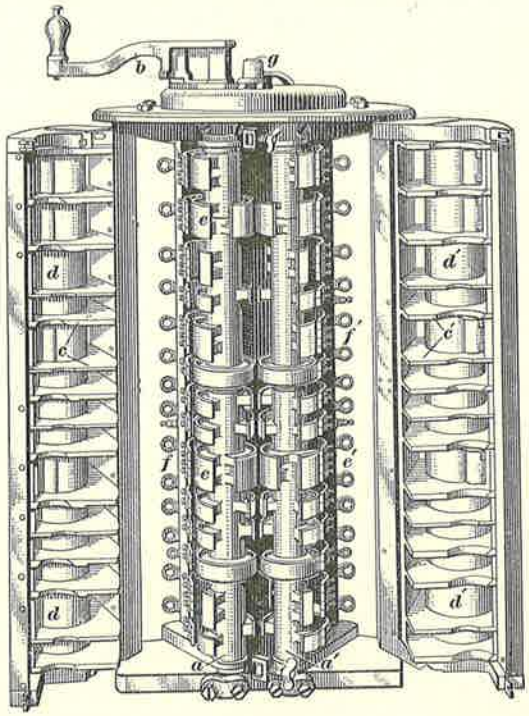


FIG. 45

fingers, are shown opened out so as to expose the contact cylinders. Each of the frames contains an iron core surrounded by a coil of wire which is protected by shields d, d' of copper or other non-magnetic material. The shields come very close to the contact segments e and fingers f, f', so that when a circuit is broken the arc at the break is transferred to one of the metallic shields d, is forced across the magnetic field set up by the blow-out coil, and is broken at the outside of the shield without

damage to the controller contacts. The shields do not show appreciable wear or burning with ordinary use, even though the controller carries very heavy currents. The handle g of the reversing cylinder is constructed in such a manner that it cannot be removed except at the off-position. The reversing and contact cylinders are interlocked, so that if the reversing handle is at the off-position the controlling handle cannot be moved, while if the controlling handle is in any of the operating positions, the reversing handle cannot be moved. On each controller frame there is a terminal connected through a 5-ampere fuse to earth, in order to protect exposed parts of the controller from high pressures.

99. Reversing Cylinder.—On each controller is a small reversing cylinder, which has contacts arranged to supply current to the operating solenoids of electromagnetic reversers under the floor of the coach. The operating solenoids of two reversers are connected in series across the line so that the reversing cylinder must provide circuits for four pairs of reversers, each motor having its own reverser. In Fig. 46, the reversing cylinder d is shown between the two controller cylinders e and f. The contact fingers will bear against the contact strips of the reversing cylinder, as shown on motor coach *1*, when the direction of running is forward, and the corresponding contacts and fingers on the opposite side will be in use for reverse running.

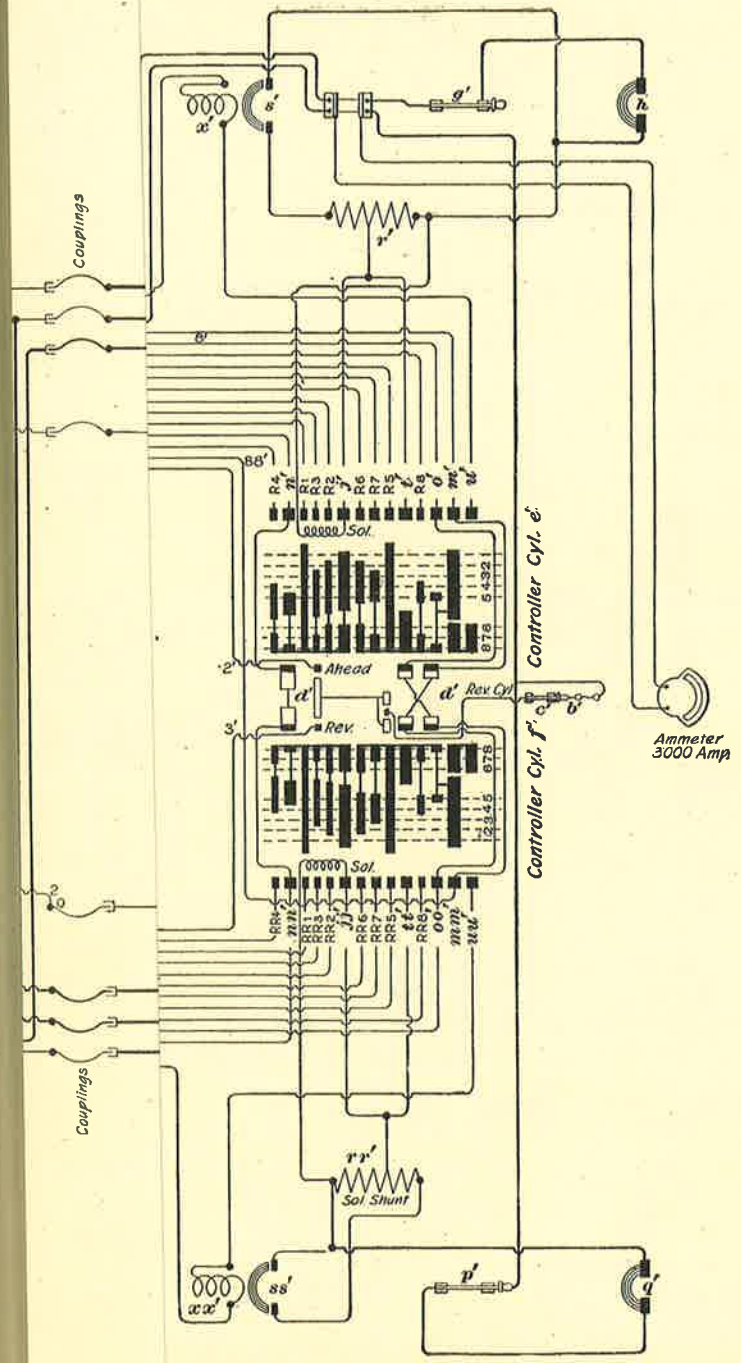
100. Reverser.—The reverser used with the direct multiple-control system is the same as that used on the multiple-unit control system, and is similar in construction to the Dick-Kerr contactor previously described. Each reverser is provided with a metallic-shield blow-out coil, as *l1*, Fig. 46, joined in series with the motors, and a number of operating coils which are provided with connections through the reversing cylinder on the controller. Two of the reversers on each motor coach are provided with five contactors in order that the four motors may be connected in two groups of two in series. Where the reverser has only four contactors, one terminal of the motor is permanently grounded, but if five contactors are used, the ground connection of the motor is made through the controller. The coils operating

the reverser contactors are numbered the same as the contactors. In series with the control coils of each pair of reversers are the contacts of two overload circuit-breakers, as *k1* and *k2*, the tripping coil of each circuit-breaker being connected in series with one of the motors so that an overload on either motor of a pair will cause a circuit-breaker to open, and thus cut out the motors by opening the reverser contacts.

101. Wiring Diagram. — In the diagram of connections, Fig. 46, for the Dick-Kerr direct multiple-control system applied to two motor coaches, the controller cylinders are represented in horizontal positions at each end. The corresponding parts of the wiring of the two motor coaches are represented by the same letters, but primes (′) are used on all letters and numbers referring to motor coach *2*. Each motor and its reverser are marked, as are the resistances, in order to facilitate tracing the circuits. Earth connections are indicated by the letter *G*, followed by numbers and letters to indicate different positions or circuits.

102. Operation of Reversers.—When the reversing cylinder *d* is in the ahead position, as shown in the controller diagram at the left of Fig. 46, current flows from the contact shoe *1*–wire *1*, *1*–ammeter shunt *a*–wire *1*–fuse *b*–switch *c*–contacts of reverse cylinder *d*–wire *2*, *2*, *2*–operating coils *2* and *4* on reverser *2*–operating coils *2*, *4*, and *5* on reverser *1*–contacts of overload release *k1*–overload release *k2*–earth at *G a*. The reversers of motors *3* and *4* are operated from wire *2* in the same manner as the reversers of motors *1* and *2*. The reversers of the second motor coach are operated by wire *2* in the train cable, which connects to wire *3′* on the second coach, to which the operating coils *1′* and *3′* on each reverser are connected. The contactors on each reverser corresponding to the magnet coils which are excited will close, and all the motors are properly connected to receive current through the main-contact cylinders of the controller on coach *1*.

103. Operation on Series Positions.—When the controller cylinders *e* and *f* of motor coach *1*, Fig. 46, are turned so that



MOTOR COACH 1

MOTOR COACH 2

Contact Shoe

Contact Shoe

Couplings

Couplings

Couplings

Couplings

Motor 2

Motor 3

Motor 4

Motor 4'

Motor 3'

Motor 2'

Motor 1'

Reverser 2

Reverser 3

Reverser 4

Reverser 4'

Reverser 3'

Reverser 2'

Reverser 1'

Controller Cyl. e'

Controller Cyl. f'

Ahead

Rev.

Rev Cyl.

Sol.

Sol.

Sol Shunt

Ammeter 3000 Amp

FIG. 46

§ 70

the reverser contactors are numbered the same as the contactors. In series with the control coils of each pair of reversers are the contacts of two overload circuit-breakers, as *k1* and *k2*, the tripping coil of each circuit-breaker being connected in series with one of the motors so that an overload on either motor of a pair will cause a circuit-breaker to open, and thus cut out the motors by opening the reverser contacts.

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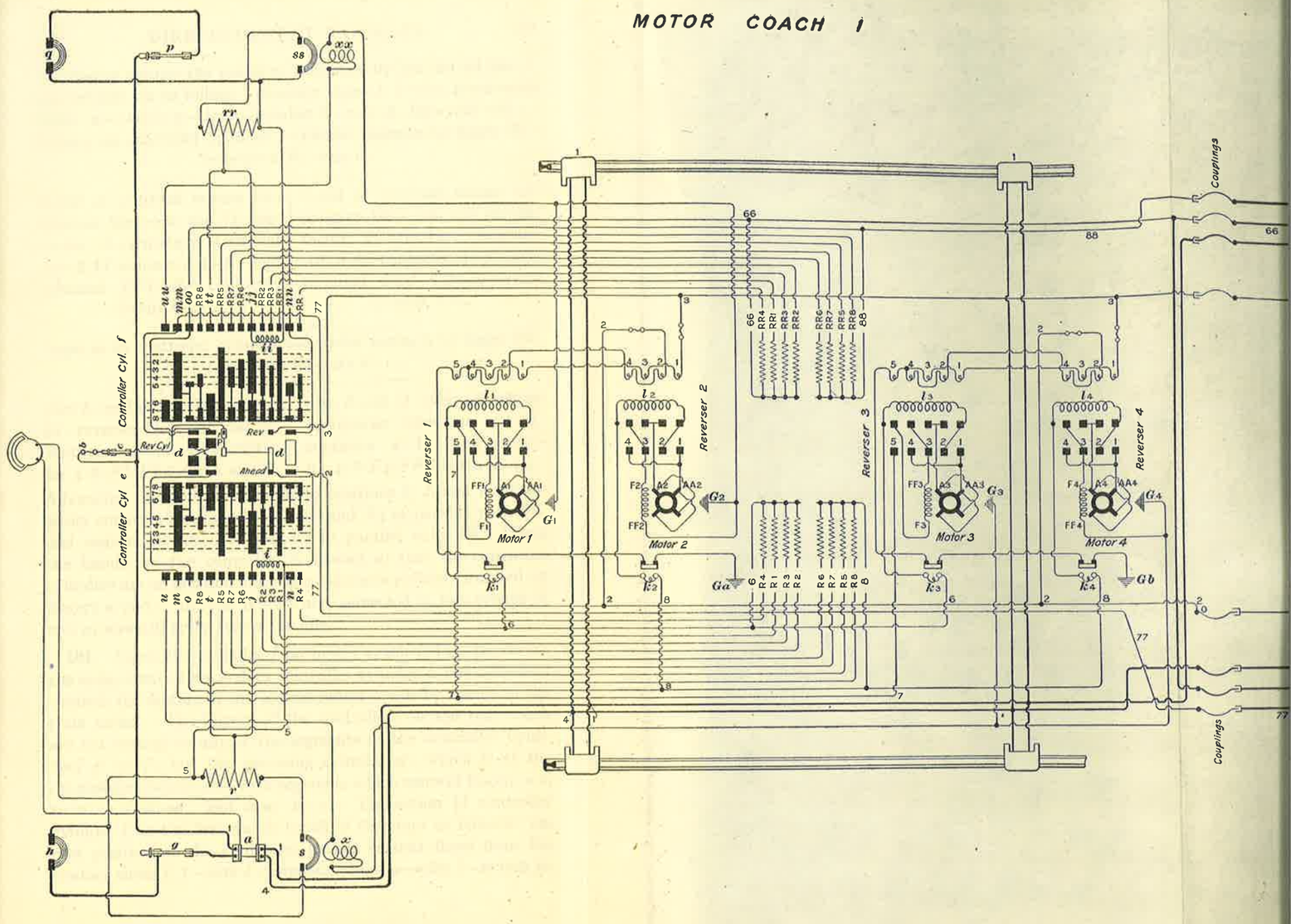
102. Operation of Reversers.—When the reversing cylinder *d* is in the ahead position, as shown in the controller diagram at the left of Fig. 46, current flows from the contact shoe *1*–wire *1*, *1*–ammeter shunt *a*–wire *1*–fuse *b*–switch *c*–contacts of reverse cylinder *d*–wire *2*, *2*, *2*–operating coils *2* and *4* on reverser *2*–operating coils *2*, *4*, and *5* on reverser *1*–contacts of overload release *k1*–overload release *k2*–earth at *G a*. The reversers of motors *3* and *4* are operated from wire *2* in the same manner as the reversers of motors *1* and *2*. The reversers of the second motor coach are operated by wire *2* in the train cable, which connects to wire *3′* on the second coach, to which the operating coils *1′* and *3′* on each reverser are connected. The contactors on each reverser corresponding to the magnet coils which are excited will close, and all the motors are properly connected to receive current through the main-contact cylinders of the controller on coach *1*.

103. Operation on Series Positions.—When the controller cylinders *e* and *f* of motor coach *1*, Fig. 46, are turned so that



the fingers occupy the positions indicated by the dotted line *1*, the circuits are as follows: Contact shoes *1*, *1*–wire *4*–ammeter shunt *a* – switch *g* – circuit-breaker *h* – wire *5* – blow-out coil *i* – finger *j* on controller cylinder *e*–cylinder contacts to finger *R1*–resistance *R1*–wire *6*–

6–coil of overload release *k1*–reverser blow-out coil *l1*–contactor *2* – armature terminal *A1*–*AA1*–contactor *4* – *3* – field terminal *FF1* – *F1* – contactor *5*–wire *7*–*7*–

6–coil of overload release *k3*–reverser blow-out coil *l3*–contactor *2* – armature terminal *A3*–*AA3*–contactor *4* – *3* – field terminal *FF3* – *F3* – contactor *5*–wire *7*–*7*–

finger *m* on controller cylinder *e*–cylinder contacts to finger *R5*–resistance *R5*–wire *8*–

wire *8* – coil of overload release *k2* – reverser blow-out coil *l2* – contactor *2*–*A2*–*AA2*–contactor *4*–*3*–*F2*–*FF2*–earth at *G2*.

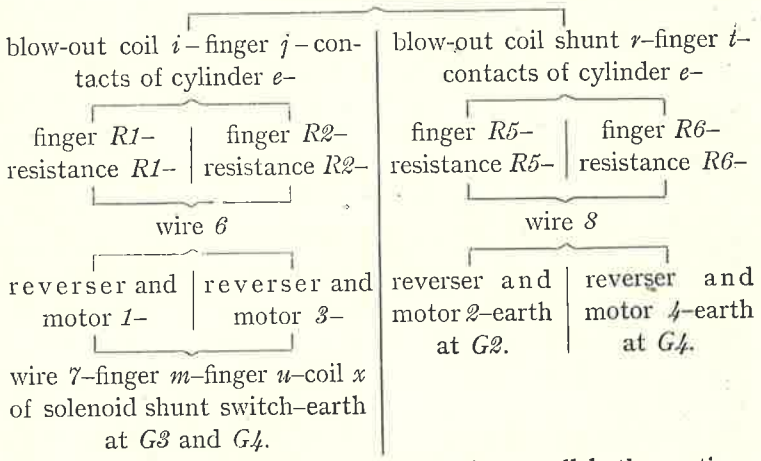
wire *8*–coil of overload release *k4*–reverser blow-out coil *l4*–contactor *2*–*A4*–*AA4*–contactor *4*–*3*–*F4*–*FF4*–earth at *G4*.

Advancing the controller handle to positions *2*, *3*, and *4* successively connects resistances *R2*, *R3*, and *R4* in parallel with *R1*, and resistances *R6*, *R7*, and *R8* in parallel with *R5*. When the handle of the controller is moved so that the controller cylinders are on position *5*, all the resistance is short-circuited by fingers *n* and *o*, and the motors are connected in two groups of two in series directly across the line.

104. Controller cylinder *f* on motor coach *1*, Fig. 46, makes the same connections as does controller cylinder *e*, but cylinder *f* controls the motors of the second motor coach by means of the train cables. The fingers of the controllers on the rear coach are not resting on any of the segments of the controller cylinders *e'* or *f'*, but the reversing cylinder *d'*, which is at the off-position, is provided with segments which connect fingers *n n'* to *n'*, *o o'* to *m'*, and *m m'* to *o'*. The action of controller cylinder *f* on the first motor coach is therefore as follows: On first position of the controller handle current flows from the contact shoes *1*, *1* – wire *1* – ammeter shunt *a* – wire *1* – switch *p*–

circuit-breaker *q*–blow-out coil *i i*–finger *j j*–contacts of cylinder *f*–finger *RR1*–resistance *RR1* on first motor coach–wire *66*–train cable wire *66* – wire *66′* on second motor coach–contact finger *n n′* on controller cylinder *f′* of the second motor coach–contacts on reversing cylinder *d′*–finger *n′*–wire *6′*–reversers and motors *1′* and *3′* in parallel–wire *7′*–contact finger *m′*–contacts of reversing cylinder *d′*–finger *o o′*–wire *77′*–wire *77* on motor coach *1*–contact finger *m m* on controller cylinder *f*–contacts of cylinder *f*–finger *RR5*–resistance *RR5*–wire *88*–wire *88* in train cable–wire *88′* of motor coach *2′* – contact finger *m m′* on cylinder *f′*–contacts of reversing cylinder *d′* – contact finger *o′* – wire *8′*–reversers and motors *2′* and *4′* of the second motor coach in parallel–earth at *G′2* and *G′4*.

105. Operation on Parallel Positions.—When the cylinders *e* and *f*, Fig. 46, of the controller on motor coach *1* are turned to position *6*, the motors of both motor coaches are connected in parallel. The circuits for the motors on motor coach *1* are as follows: Contact shoe *1*–ammeter shunt *a*–switch *g*–circuit-breaker *h*–wire *5*–


blow-out coil *i* – finger *j* – contacts of cylinder *e*–
finger *R1*– resistance *R1*–
finger *R2*– resistance *R2*–
wire *6*
reverser and motor *1*–
reverser and motor *3*–
wire *7*–finger *m*–finger *u*–coil *x* of solenoid shunt switch–earth at *G3* and *G4*.
blow-out coil shunt *r*–finger *i*–contacts of cylinder *e*–
finger *R5*– resistance *R5*–
finger *R6*– resistance *R6*–
wire *8*
reverser and motor *2*–earth at *G2*.
reverser and motor *4*–earth at *G4*.

The closing of the solenoid shunt switch *s* parallels the sections of the solenoid shunt *r* and thus prevents too great a current from flowing through the blow-out solenoid *i*. On position *7* resistances *R1*, *R2*, *R3*, and *R4* are in parallel with each other and in series with motors *1* and *3*, which are in parallel with each other. In like manner the resistances *R5*, *R6*, *R7*, and *R8* are all in parallel and in series with motors *2* and *4*, which are in parallel. When the handle of the controller is moved to its final position, all the resistance sections are short-circuited and the motors are all in parallel across the mains. The motors of the second motor coach are operated by controller cylinder *f* in the same manner as the motors of the first coach are operated by controller cylinder *e*.

CONDUCTOR RAILS AND TRACK CONSTRUCTION

CONDUCTOR RAILS

CONDUCTIVITY PROTECTION AND BONDING

106. Supply Conductors.—Direct current is generally supplied to trains on electric railways by an insulated third rail, and either the track rails or a separate fourth conductor rail forms the return. Overhead trolley wires are sometimes used, in which case the construction is similar to that employed for tramways, unless the voltage of the system and the speed of the trains are very high, in which case a special construction is adopted. Conductor rails may be of the regular shape used for track rails, but are often of rectangular or channel cross-section. Table II gives some particulars of the conductor rails, etc., used on the principal British direct-current railways.

107. Conductivity of Steel Rails.—The specific resistance of steel increases somewhat with the percentage of carbon. The presence of manganese in iron also has the effect of increasing the resistance, but in a varying degree, the higher percentages having a greater effect. By properly adjusting the percentages of carbon, manganese, etc., special steels can be made which have a specific resistance only 7 or 8 times that of copper. For example, steel which, when analyzed, shows percentages not exceeding ·15 for carbon, ·3 for manganese, ·06 for phosphorus,

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TABLE II

PARTICULARS OF CONDUCTOR RAILS, INSULATORS, AND MOTORS OF DIRECT-CURRENT ELECTRIC RAILWAYS IN GREAT BRITAIN

Name of Railway	Weight of Third Rail Lb. Per Yd.	Position of Third Rail	Return Conductor	Position of Return Conductor	Third-Rail Insulators	System of Control	Number of Motors on Each Coach or Locomotive	Rated Horse-power of Each Motor
City & South London . .	40	Between track rails	Track rails		Glass	Series parallel	2	
Liverpool Overhead . . .	70	Centre of track	Track rails		Stoneware	Series parallel	2 and 1	100
Waterloo & City, London .	80	Centre of track	Track rails		Stoneware	Series parallel	2	60
Central London	104	Centre of track	Track rails		Stoneware	B.T.H. multiple unit	2	65
Mersey Tunnel	100	Centre of track	Insulated 4th rail	Centre of track	Vitrified clay	Westinghouse multiple unit	4	100
Great Northern & City, London	80	Outside track	Insulated 4th rail	Opposite side of track	Stoneware	B.T.H. multiple unit	2	125
Liverpool to Southport Section, Lancashire & Yorkshire	70	Outside track 3′ 11½″ from centre	Uninsulated 4th rail	Centre of track and bonded to track rails	Stoneware	Dick-Kerr direct multiple	4 or 2	150 or 125
Tyneside Lines of North Eastern	80	Outside track 3′ 11½″ from centre	Track rails		Reconstructed granite	B.T.H. multiple unit	2	125
Metropolitan, London . .	100	Outside track	Insulated 4th rail	Centre of track	Stoneware	Westinghouse and B.T.H. multiple unit	4	200 or 150
Metropolitan District, London	100	Outside track 3′ 8¼″ from centre	Insulated 4th rail	Centre of track	Stoneware	B.T.H. multiple unit	2	200
Baker Street & Waterloo, London	85	Outside track 6″ from track rail	Insulated 4th rail	Centre of track	Stoneware	B.T.H. multiple unit	2	200
Great Western & West London	100	Outside track 1′ 4″ from track rail	Insulated 4th rail	Centre of track	Vitrified porcelain	B.T.H. multiple unit	4	150
Great Northern, Piccadilly, & Brompton, London	85	Outside track 6″ from track rail	Insulated 4th rail	Centre of track	Vitrified porcelain	B.T.H. multiple unit	2	200
Charing Cross & Hampstead, London	85	Outside track 6″ from track rail	Insulated 4th rail	Centre of track	Vitrified porcelain	B.T.H. multiple unit	2	200

·06 for sulphur, ·05 for silicon, has a resistance about 8 times that of copper. On the Central London Railway the third-rail conductor has a resistance 7½ times that of copper of equivalent area.

108. Protection of Conductor Rails.—Near stations and at crossings it is necessary to protect the third, or conductor, rail so as to reduce the danger to anyone who may walk on to the track from the station platform or the crossing. The method generally used in Great Britain is shown in Fig. 47 (*a*) and (*b*). Planks *a* are bolted to the distance pieces *b*, which rest against the rail so that the top edges of the planks stand several inches above the top of the rail and at a sufficient distance from it to clear the collector shoe. In the United States this method of protection gives more trouble than in Great Britain, because of

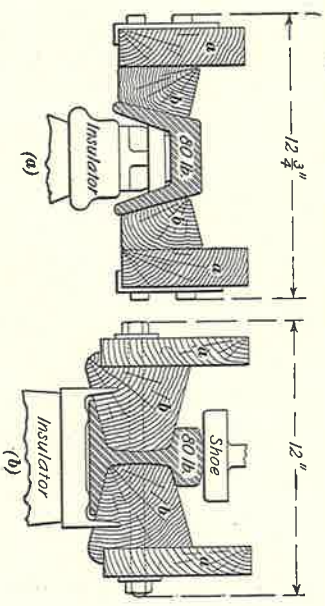


Fig. 47

snow and sleet which sometimes form on the top of the conductor rail. The planks are therefore fixed over the top of the conductor rail and current is picked up by means of a shoe which projects under the protective covering of the rail.

109. Protected Bond for Conductor Rail.—Bonding is the method generally used for connecting the sections of conductor rails, because, owing to the rails being uncovered, there would be trouble with expansion and contraction if the joints were welded. The currents used are much greater than in tramway work, and therefore the bonds must be of greater section, but otherwise they are similar. Fig. 48 shows the protected type of bond as used on a conductor rail having the same shape as the track rails. The bond is made of copper strips *a* cast into solid copper

ends *b*, which are expanded tightly into the web of the rail. After being fixed in position the bonds are covered by the fish-plates *c*. In some cases the terminals of rail bonds are electrically welded to the rails, instead of being expanded into holes drilled in the web or flange of the rail.

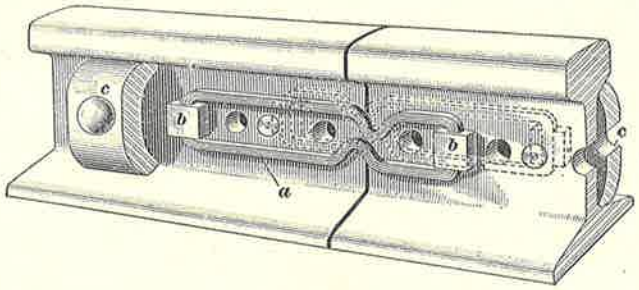
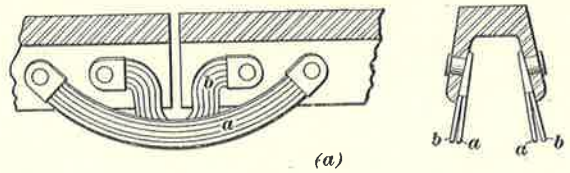


FIG. 48

110. Unprotected Bonds for Conductor Rails.—Owing to the fact that a conductor rail is usually at a potential of 500 volts or more above the earth potential, the bonds cannot be removed



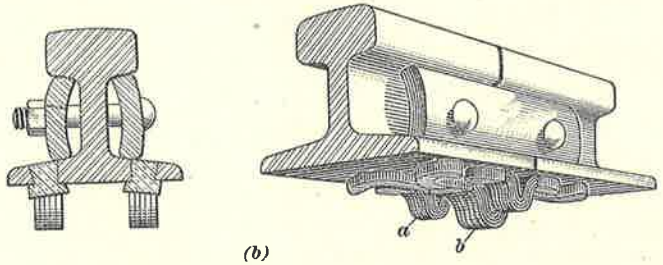


FIG. 49

easily or safely, and therefore need not be protected by fish-plates to prevent their removal by unauthorized persons. The unprotected type of bonds can be made more flexible than the

protected type, and therefore will permit of greater movement between the adjacent rail ends without injury to the connections. In Fig. 49 (*a*) is shown a double flexible bond for a channel conductor rail. The bond consists of two flexible conductors *a* and *b* joined to terminals which are expanded into the flange of the rail. Fig. 49 (*b*) shows a form of flexible bond fitted to the flange of a conductor rail. As in the previous case, there are two shapes of bonds used, as shown at *a* and *b*. The cross-sectional view shows the way in which the bond terminals are expanded into the rail flange.

111. Feeder Connections.—In all cases where a break is made in the conductor rail, the ends must be joined by means of an underground cable. Various methods of running the cable are used. In the method shown in Fig. 50, each end of the cable is carried through a heavy porcelain insulator *a* set in an iron pipe *b*. The strands of the cable *c* are soldered into a terminal casting *d*, and after the lower part of the insulator has been plugged with hemp the space is filled with insulating compound to prevent moisture from entering and injuring the paper insulation of the cable, which, in this case, has a lead sheath covered with jute treated with asphalt. A brass cap *e* is bolted to the cable terminal, and from it two flexible bonds are connected to the rail.

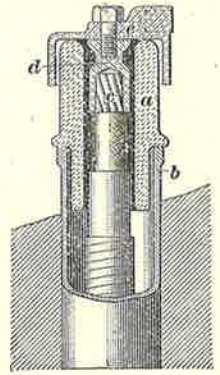


FIG. 50

JUNCTIONS

112. Continuity of Current Supply.—At crossings and junctions the presence of the third rail causes difficulties which are not experienced in overhead systems. It is, of course, impossible to preserve the continuity of the conductor rails at junctions. On tube railways in Great Britain, where bus-lines connecting the collector shoes on different motor coaches are not permitted, the circuit must often be broken at junctions. Where a bus-line is provided, it is practicable in most cases to bridge the

gap, the shoe on the forward car making contact with the rail before the shoe on the rear car has reached the gap. In order that the shoe may come into contact with the conductor rail without a jerk, the rail is tapered on each side of every gap, and by this means the shoe is gradually raised. In many cases the vertical travel of the shoe is $\frac{3}{4}$ inch on each side of its mean position, and a taper of 1 in 24 is commonly adopted for the rails on each side of a gap; with this slope the length of the tapered portion of each rail must therefore be 18 inches.

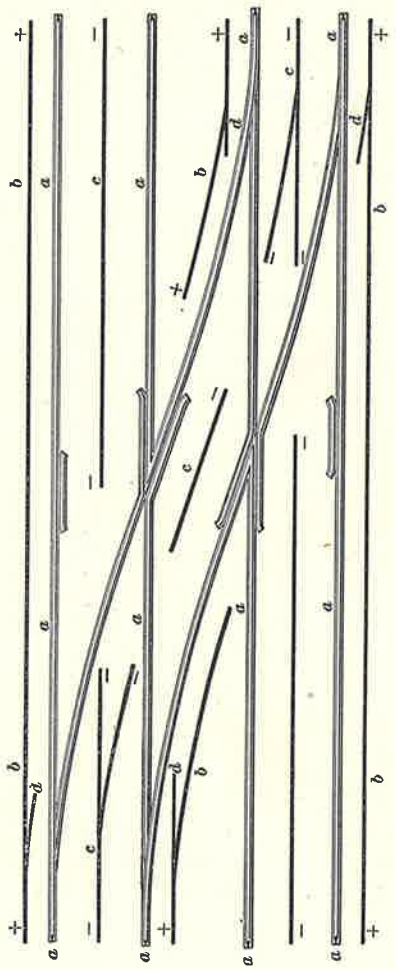


FIG. 51

113. Arrangement of Conductor Rails at Cross-Over.—The arrangement of third and fourth, or supply and return, conductor rails at a cross-over from one track to another is shown diagrammatically in Fig. 51, in which the four track rails are marked *a*, the positive conductors or third rails *b*, and the return conductors or fourth rails *c*. At four points there are special attachments *d*, forming sloping approaches to the rails *b*, whereby the collector shoes when approaching the rail are led up to the surface of that rail. Without these attachments the shoe would simply collide with the side of the rail, and one or

the other would be damaged. The positive conductor rails *b* are usually about 3 inches above the track rails, and the return conductor rails are about $1\frac{1}{2}$ inches above the track rails, so that the contact shoes will clear the track rails at cross-overs. If a coach or locomotive were not provided with collector shoes on both sides of the track, there would sometimes be difficulty in supplying current to the motors at cross-overs.

INSULATION OF CONDUCTOR RAILS

114. Forms of Insulators. — The conductor rail should be thoroughly insulated from the track rails and ground by being mounted on insulators that are strong mechanically, and which allow the conductor rail freedom for expansion and contraction. In some cases insulators made of specially treated wood, provided with an iron cap on which the rail rests, have been used, but usually the insulators are of special insulating material, such as stoneware or reconstructed granite, the latter being concrete formed from crushed granite and cement.

Fig. 52 shows a type of insulator for a conductor rail in which the insulating material is reconstructed granite. Side motion of the rail is prevented by the lugs *a* and *b*, which are held in position by a bolt *c*, which passes entirely through the upper portion of the insulator. The insulator is held to the sleeper by means of the bolted corner castings *d*. The lugs holding the rail allow a certain amount of play, as the weight of the rail is sufficient to hold it in place, and, if too tightly fastened, heavy stress, due to the expansion and contraction of the rails, is thrown on the insulators.

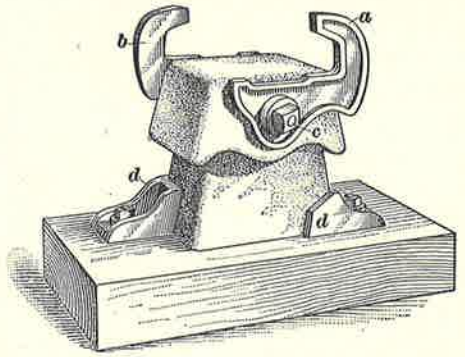


FIG. 52

115. Stoneware Insulators.—In Great Britain insulators made of vitrified stoneware have been largely used. In Fig. 53 is shown a partly sectional view of a Doulton pedestal type of insulator. The stoneware part *a* has three petticoats to shed off any moisture, and it is held from moving on the sleeper by the malleable iron castings *b*. The conductor rail is held in position by a cap or chair *c* of suitable shape, made of malleable iron, provided with a stem which is cemented into a recess in the insulator.

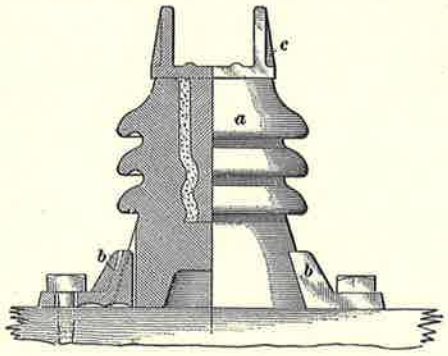


FIG. 53

Fig. 54 shows a Doulton fourth or negative return conductor, rail insulator of the type used on the Metropolitan & District Railway of London. It is much shorter than the third-rail insulator, because the potential of the return conductor is nearly the same as that of the earth, and there is very little tendency for leakage to occur. The rail is held in position by lugs on an iron cap *a* which fits over the stoneware body *b*. The base *c* is provided with three holes for screws to fasten it to the sleeper and with a stem, which is cemented into a hole in the centre of the stoneware body *b*. If the rail expands, it slides on the ribs provided on the cap of the insulator, and thus avoids producing undue stresses in the insulating material. Side motion of the rail is prevented by the lugs.

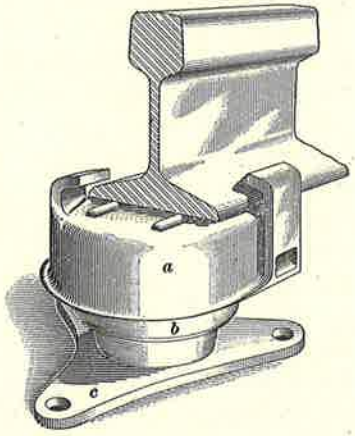


FIG. 54

TRACK CONSTRUCTION

116. Track Rails.—For track rails the first requirement is, of course, mechanical strength, and when used to carry the return current their electrical properties must be subordinate to mechanical qualities. The resistance of the track may be made low enough to keep the voltage drop within a reasonable limit if the joints are carefully bonded. It is usual, in addition to the bonds at the rail joints, to run an extra conductor which connects to the two track rails at frequent intervals and aids in equalizing the flow of current. Since high-conductivity iron does not possess sufficient strength, the track rails have usually a specific resistance about 12 times that of copper, and manganese steel, which is used for special work, has a still higher resistance.

117. Board of Trade Regulations.—The rules given by the Board of Trade for governing the construction and arrangement of the permanent way and stations of tube railways are as follows :

1. Sleepers to be of hard wood, not creosoted, and to be laid in concrete or ballast, and covered with a layer of gravel or finely broken stone free from dust, the ballast to be finished to a level surface so as to form a convenient roadway for passengers in case of emergency. If ballast is not used, the space between the rails to be covered with granolithic slabs, or slabs of a similar material, to form as wide a roadway as possible for passengers. No timber planks to be used.

2. Tunnels to be provided with lights capable of being turned on from the stations at either end of each section, and, if necessary, at some intermediate points. The lighting circuits to be independent of the traction supply.

3. Separate entrances to and exits from each platform of the stations to be provided, and to be situated as nearly as possible in the middle of the platforms.

4. All stairways, passages, and exits from the stations to be conspicuously lighted. Not less than 25 per cent. of the lights in these places to be supplied from independent source. If necessary, the exits to be made more conspicuous by the use of coloured lights in addition to white lights.

5. Platforms not to be made of wood, and woodwork to be eliminated as far as possible from signal boxes, lifts, offices, etc., below ground.

6. Efficient hydrants, hose, and fire-prevention appliances to be provided.

7. Ventilating ways to be provided wherever possible from the station and the tunnels to the surface.

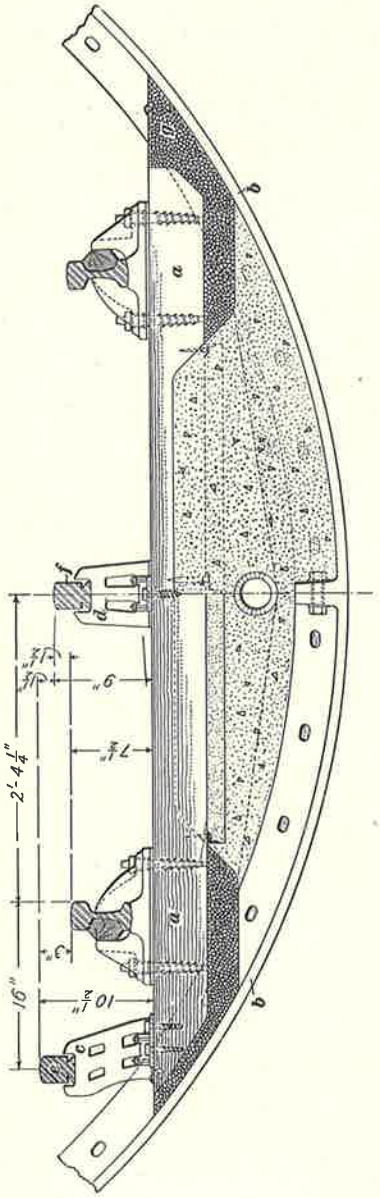


Fig. 55

118. Track Construction for Tube Railways.—The tunnels of the tube railways in London are lined with cast-iron segments *b* bolted together and made water-tight with rust cement. As the space available is very limited, there is not room enough for the usual ballast and sleeper construction of the track. When the first tube railways were built, cross or longitudinal sleepers resting against the walls of the tunnels were used, but in some cases this construction caused the vibration of passing trains to be communicated to neighbouring buildings. The special construction shown in Fig. 55, which shows a partial cross-section of the Baker Street & Waterloo Railway, was therefore adopted. The bottom of the tube is filled with concrete, and sleepers of hard wood are laid in it, the ends projecting as shown at *a*. Under these projecting ends crushed granite is packed to give the roadbed elasticity. Some of the sleepers are long and carry stoneware insulators *c* and *d*, which

support the third and fourth conductor rails *e* and *f*. These conductor rails weigh 85 pounds to the yard, and in order to give less jar or vibration on the insulators, felt pads are placed between the insulators and the sleepers.

119. Standard Dimensions.—As it is desirable that, on main-line railways, a train built for one railway shall be able to run on any other, a conference of British railway companies was held in 1903 to consider the best position for conductor rails, so as to secure uniformity. Fig. 56 shows the arrangement adopted. The track rails are indicated at *a*, the third rail, or

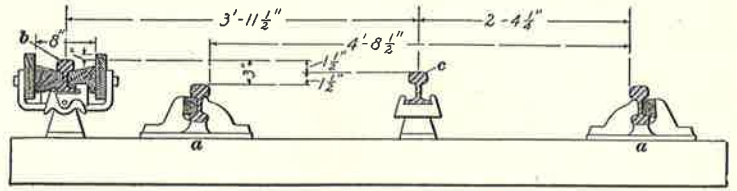


Fig. 56

supply conductor, at *b*, and the fourth rail, or return conductor, at *c*. Both the third and fourth rails are on insulators, the top of the third rail being 3 inches and the top of the fourth rail being $1\frac{1}{2}$ inches above the track rails. On many railways this standard arrangement has been adhered to, but in the confined space of some of the tube railways in London the dimension between the third rail and the centre of the track is less than 3 feet $11\frac{1}{2}$ inches. On the Liverpool & Southport branch of the Lancashire & Yorkshire Railway the fourth rail is uninsulated, and each rail length is bonded to the track rails.